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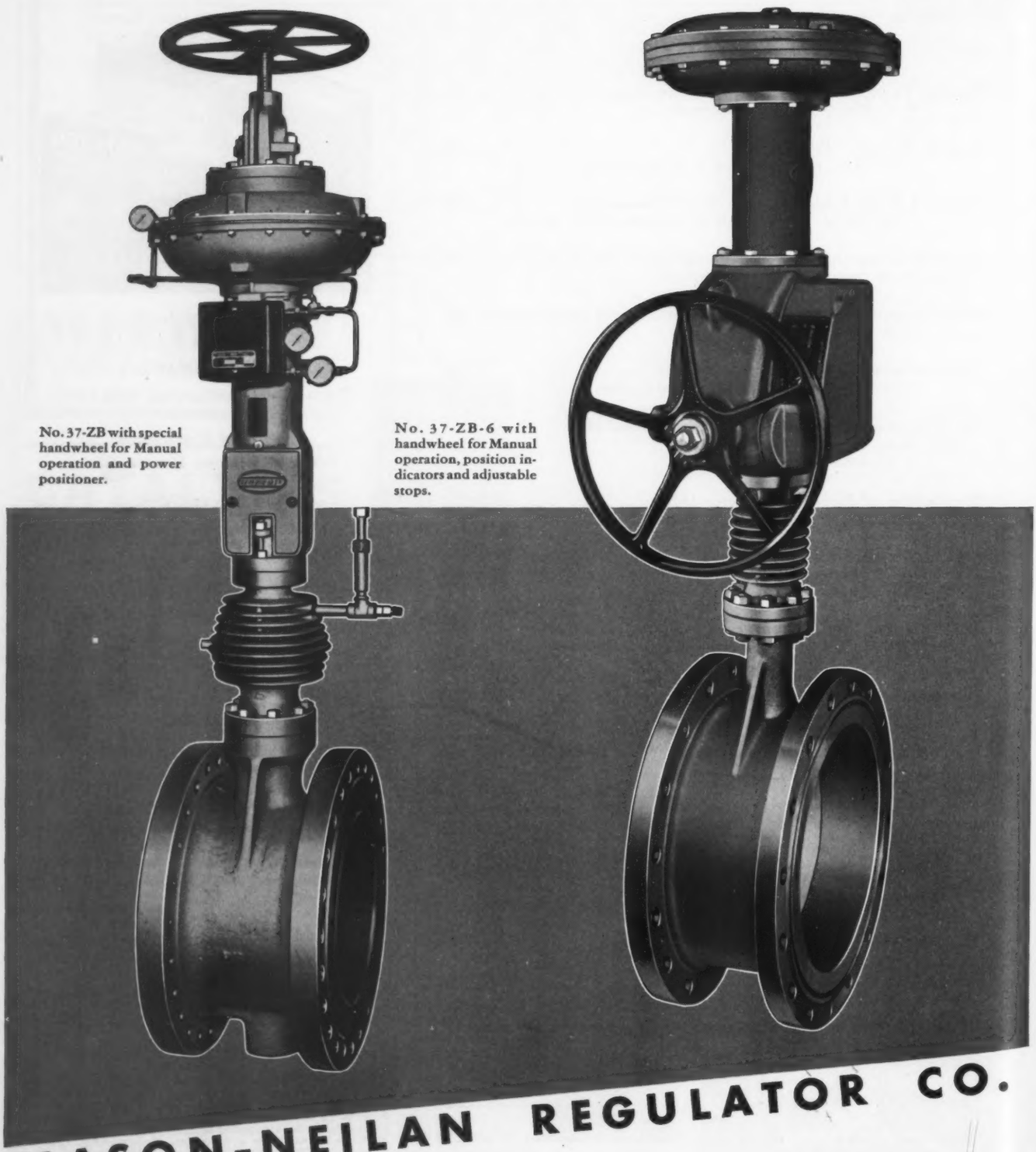
# Where Plenty of Gas



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VOLUME 20, No. 11 NOVEMBER, 1941

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# The Look Box

IT IS a weakness of men that they hear the pleasant and ignore the unpleasant. This frailty lies behind the encouragement that came when Harold L. Ickes, Petroleum Coordinator for National Defense, added this sentence to his talk only a few hours before he appeared at the first general session of the twenty-second annual meeting of the American Petroleum Institute: "I view the office of Petroleum Coordinator as an emergency created to do a necessary work during an emergency—an agency that will be discontinued when the emergency ends."

**Federal Control**

It is no secret that the petroleum industry fears and anticipates federal control. That sentence was accepted almost as assurance that federal control is no longer to be feared. It is a false conclusion. No doubt the office of petroleum coordinator will end with the emergency. That, however, may have little influence on federal control.

Fortunately much of the talk by Coordinator Ickes dealt with the possibilities of federal control. He said emphatically: "I have neither the power nor the will to impose federal control upon the oil industry."

Despite these expressions he gave the industry reason to take stock of itself, the public and the government. The petroleum coordinator placed responsibility for federal control, should it come, upon the industry with this conclusion:

"What I am leading up to is that if the federal government ever imposes any measure of control over the oil industry it will be in the interest of conservation. Wasteful practices, sooner or later, bring some type of federal control. And wasteful practices in the oil industry will also bring some measure of control, probably not during my tenure of office, but yet surely and inevitably. The way—the only way—in which to make unnecessary such control as will prevent waste and intemperate exploitation will be for you to exercise that measure of self-control which will persuade the government that you are managing your own affairs so competently, so wisely and so patriotically as to make unnecessary any interference by the people."

There is a curious contrast of words in the paragraph. It has been the accepted procedure in this country that legislation such as control over an industry comes about by a demand from the public. The Petroleum Coordinator ended his paragraph with "by the people." Elsewhere, he advised the industry to adjust its methods to please the government.

Should this administration or any other administration wait for the voice of the people, control of the industry is unlikely. The public has had much from the industry and the prospect is that it will have more. It gets a better product at a lower price. There is no public demand for control of the industry. The subject has consideration in only two spots, within the industry and in Washington.

The Petroleum Coordinator singled out California and Illinois as instances of wasteful methods. It would be a help if the instances could be segregated even in those states and brought down to fields. And better still if methods of preventing the waste could be offered.

In this country there is no waste of oil. It is being used to the last barrel. Field practice may

not be uniformly as advanced as is scientific investigation. But as the industry learns it adopts and thus keeps pace with science.

## Another Horse And Buggy Age?

THE automobile is the individual's outstanding machine and thus his outstanding conflict with the defense program. For the automobile owner the defense program means not only a shortage of new cars but also a readjustment in the supplies necessary for the old ones. Motor fuel, rubber, anti-freeze, parts and finishes all present problems.

"One need not enter the controversy as to the adequacy now of motor fuel supplies in consuming areas. Regardless of the present situation, future supplies will depend on the rate tankers are eliminated; the scale of operations of motorized military units and of shipping; the destruction of Allied oil facilities; and the construction of new petroleum transport facilities. With these uncertainties assurance of an adequate continuing supply is lacking.

"Less publicized is the threat to quality. Tripling of aviation gasoline production is now demanded by defense authorities and still further expansion may be required as the tempo of air and tank operations increases. This may cause some diversion of appropriate petroleum fractions and special high-octane equipment. Aviation requirements for ethyl fluid and a shortage of chlorine, needed for its manufacture, may reduce the civilian's supply of ethyl. Presumably, however, both possibilities could only eliminate premium motor fuel and slightly reduce the octane rating of other grades, enough only to take some of the "zip" and a little of the efficiency from automobile operation.

Next to fuel, rubber is the car owner's largest purchase; present imports are above normal, but at any moment may be severely cut. Synthetic rubber production is increasing steadily but is too small to supply civilian needs during a war emergency. Rubber companies have been restricted to their normal consumption of 600,000 tons a year, from which they must fill both defense and expanded civilian requirements. Retreading is one outstanding means of meeting the pinch by spreading the use of the available rubber. After receiving a new tread, using about 8 pounds of rubber, the old tire, which contained some 15 to 20 pounds of rubber, is reported good for perhaps three quarters of the life of the original tire, provided the side walls and textile casing have not been damaged. Retreading can be done in a properly equipped service station in 24 hours and may cost half the original tire price. The economy of retreading has long been recognized by owners of truck and bus fleets, but it may take the present possible rubber shortage to bring this saving home to the pleasure-car owner.

"Anti-freeze brings to the motorist the defense problems of the chemical industry. Ethyl alcohol, methyl alcohol and ethylene glycol, the three substances which commonly keep our cars from freezing, have all been placed under priority control. Methyl alcohol, a raw material in the manufacture of formaldehyde required for plastics production, is the tightest. Last year methyl alcohol, principally in branded products, had about one third of the anti-freeze market; this year defense will absorb the entire methyl alcohol output, leaving only the small amount already distributed to dealers for the motorist. Ethylene glycol, the non-evaporating anti-freeze, will be more available for anti-freeze use than methyl alcohol. However, manufacture of ethylene glycol is hampered by the diversion of raw materials to defense use and it is itself on the priority list because of its use in liquid-cooled Allison and Rolls-Royce engines, army trucks and jeeps. Ethyl alcohol, which comprised half of last year's anti-freeze supply, has been put under priority control because of its use in smokeless powder manufacture and the rising general industrial demand. However, plans for production of 50,000,000 gallons of industrial alcohol in whiskey distilleries indicate the possibility of an adequate supply this winter. Ethyl alcohol will thus probably be an even more important anti-freeze. In spite of probable shortages, anti-freeze prices have not risen.

"There is no indication of a shortage of replacement parts needed by older cars. Automobiles are not among the 20 industries assigned A-10 priority for repair parts; but their inclusion seems likely. Better care means reduced need for replacements with lubrication particularly important. OPACS has suggested adherence to the 1000-mile greasing rule but only seasonal oil change.

"Refinishing may soon be a regular part of maintenance. For it the supply of nitrocellulose lacquer seems adequate but synthetic resin finishes may be made unavailable by defense needs."

*—From the Industrial Bulletin of Arthur D. Little, Inc., October, 1941.*

# Reaction Chambers on Thermal Cracking Units

R. C. MITHOFF and L. F. SCHIMANSKY
Standard Oil Company of California

**IN RECENT years the Standard Oil Company of California has installed auxiliary downflow reaction chambers on 8 cracking units having a total raw-feed capacity of approximately 90,000 barrels per day. The results have been highly satisfactory.**

**In this paper correlations are presented relating reaction-chamber size with results obtained by the use of these chambers. It is shown that their use increases the severity of cracking of the gas-oil component of the raw feed, and decreases the severity of cracking of the asphaltic component. This results in production of cracked residuum of lower sediment content and increased viscosity, and of cracked gasoline with increased volatility and higher octane number. Use of chambers also results in increased plant capacity, due to decrease in the heat requirement for cracking, to reduction in tube coking, and to improved furnace conditions.**

**These advantages result in appreciable decrease in the manufacturing cost of cracked gasoline. It is believed that installation of additional reaction chambers on many of the cracking units in use in this country would be advantageous.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 6, 1941.**

THERMAL cracking units employed by Standard Oil Company of California about 10 years ago were equipped with primary flash chambers or evaporators. The top transfer oil from the furnace was discharged, without quenching, into the evaporator wherein the vapor and liquid were separated. The overhead vapor passed directly to the fractionating column. Sufficient liquid was maintained in the evaporator to seal the bottom draw. The heavy liquid oil from the evaporator bottom passed to an auxiliary flash system. The evaporator operated at a temperature such that appreciable cracking occurred therein.

Different units, otherwise essentially identical, were equipped with evaporators ranging in size from vessels 5 feet in diameter and 37 feet high to vessels 10 feet in diameter, 30 feet high. It was observed that the units equipped with larger evaporators tended to produce more volatile gasoline of higher octane number, and were of higher capacity, than the units equipped with small evaporators. This effect was attributed to the increased amount of cracking that occurred outside of the furnace coil in the units equipped with large evaporators.

A program of laboratory experimental cracking was performed to investigate these factors. The expected effects were strikingly confirmed; i.e., coil-and-chamber cracking produced more volatile gasoline of higher octane number, and the unit capacity was greater, than in the case of coil-only cracking.

A commercial unit next was equipped with a small auxiliary downflow reaction chamber, essentially as shown in Figure 1. A test program was performed with the vessel in and out of service, and the anticipated effects of the chamber were confirmed again. Since then Standard Oil Company of California has installed auxiliary reaction chambers on eight cracking units. All of them operate essentially as shown in Figure 1. The different chambers have been in service from one to five years, and extensive commercial test data on them have been obtained.

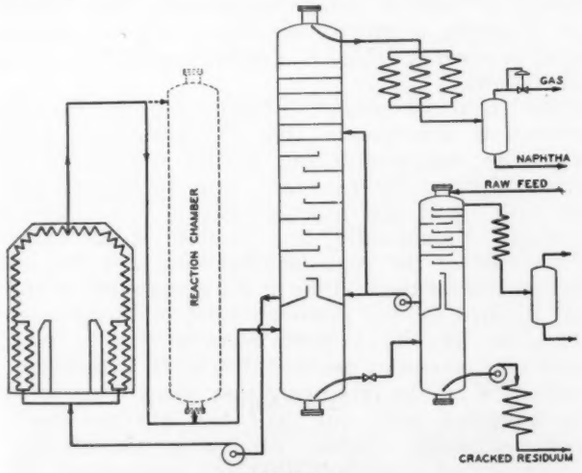


**FIGURE 1**
**Flow diagram of cracking unit.**

This paper presents a brief summary of the effects on plant operation and product quality that resulted from installation of the auxiliary chambers.

## Theory of Reaction Chambers

Cracking stock processed by Standard Oil Company of California is substantially heavier than are most of the stocks processed in the East. At different times residuums from California crudes have been cracked—these ranging in Saybolt Universal viscosity from 125 to 2500 seconds at 130° F., and in API gravity from 14 to 23 degrees. The average for these residuums is a Saybolt Universal viscosity of about 800 seconds at 130° F., and they contain approximately 45 percent of 70-penetration asphalt. This means that, with this California stock, more cracking occurs in the liquid phase than occurs with the lighter Mid-Continent or Eastern stocks; and that also, with this California stock, furnace-tubing coking is more severe than with the lighter Mid-Continent and Eastern stocks.

In a cracking unit operating without a reaction chamber, furnace conditions severe enough to obtain the desired conversion of the vaporized gas-oil component of the charging stock overcrack the heavy constituents that remain in the liquid phase in the tubes.

One method often employed to offset this disadvantage is two-coil operation, wherein a side cut from the vapor column is circulated through a light-

oil cracking furnace. However, most California charging stocks do not produce sufficient oil of appropriate boiling range for recirculation to the light-oil furnace. This situation is aggravated further by the fact that lean naphtha (often containing less than 80 percent of gasoline) must be produced in order to supply cutter stock for the heavy cracked residuum that is produced from most California charging stocks.

Use of a downflow reaction chamber on a single-coil unit effects many of the advantages of two-coil operation, without the foregoing disadvantage, when heavy oil is charged. The top transfer oil from the furnace is a mixture of liquid and vapor, and is discharged at essentially full cracking temperature into the top of the reaction chamber. The liquid constituents flow rapidly down the walls or fall through the vapor, under the influence of gravity, to the bottom of the vessel, and promptly are ejected therefrom in the combined liquid and vapor stream. However, the vaporized constituents of the oil from the furnace top transfer line drift slowly downward through the vessel, being forced forward only as additional vapor enters the top of the chamber. This situation results in exposure of the vapor in the chamber to cracking conditions for a period several times longer than exposure of the liquid. This means that, in the unit as a whole, the vapor is cracked appreciably more severely than is the asphalt —which is one of the main objectives of two-coil operation.

Use of a reaction chamber, therefore, allows the overall degree of cracking in the unit to be increased without undue coking, because the chamber permits increase in the severity of cracking of the low-coke-forming gas oil, without increase in the severity of cracking of the high-coke-forming asphalt. This results in increased unit capacity, gasoline of improved quality, and cracked residuum of lower sediment content.

Use of a reaction chamber decreases the proportion of the total cracking that must be done within the furnace coil. This markedly decreases the amount of coke deposited in the tubes, especially as it is in the later stage or coke-forming part of the cracking reaction—during which, in many cases, coke formation is heaviest—that coke is formed in the reaction chamber. Coke formation in the chamber is less harmful to economical operation of the unit than is coke formation in the furnace tubes, because more coke can be deposited in the chamber before a shut-down for cleaning is required.

Installation of a reaction chamber changes the cracking reaction from a short-time high-temperature process (as in coil-only operation) to a long-time lower-temperature process. This increases the amount of polymerization of olefinic compounds, especially those within the gasoline boiling range. The primary cracking reaction is endothermic, and polymerization is exothermic; hence, the chemical heat of reaction in the overall cracking process is reduced by installation of a chamber—and this results in increased plant capacity. The increase in polymerization also may account in part for the improvement in the octane number of the gasoline.

Use of reaction chambers decreases the net heat requirement for cracking more than can be accounted for by decrease in the chemical heat of reaction. This is due to increase in the volatility of the naphtha and cracked residuum—which lowers the temperature at which the cracked products leave the unit. In this connection it should be pointed out that ordinarily no naphtha is recirculated to the top of the vapor column in units like those shown in Figure 1 when heavy California residuums are charged.

Although use of reaction chambers is believed to increase the amount of polymerization that occurs in the unit; nevertheless, the yield of butenes per barrel of cracked gasoline is essentially unchanged. The reason for this is not clear, although it may be that in this regard the increase in polymerization is offset by the increase in severity of cracking of the gas oil.

### Method of Correlating Results

The effects of reaction chambers described hereinbefore are truly a result of change in the time-temperature relation for the gas-oil and asphalt components of the furnace feed. Complete correlation of the effects of the chamber, of course, would have to include calculation of the change in time-temperature

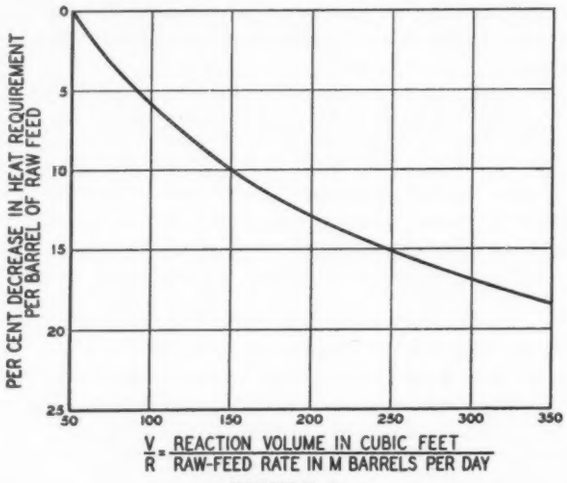


**FIGURE 2**

**Effect of reaction volume on total heat requirement of cracking per barrel of raw feed.**

relation for both of these components. This calculation, however, would be laborious; and its accuracy would be questionable. A simpler correlation factor is desirable.

After trial of many different factors for this purpose, it was found that the quotient of the volume in which cracking occurs outside of the furnace divided by raw-feed rate correlated quite well with all of the observed effects of addition of chambers. Numerically, this quotient is the sum of the volume of the reaction chamber, in cubic feet; plus one half of the volume of the evaporator in cubic feet; divided by the raw-feed rate, in thousands of barrels per day. These units were adopted to give a factor of convenient numerical size. It is designated herein as $V/R$. In this expression, evaporator volume was assigned only one half the effectiveness of reaction-chamber volume; because it was observed, in commercial operation, that the evaporator operated at lower temperature than did the reaction chamber, the difference being such that about one half of the reaction rate would be expected.

The relation between severity of cracking of the gas oil and asphalt is also dependent upon the shape of the auxiliary reaction vessel employed. The time that the gas oil spends in the vessel is dependent upon the volume of the vessel; whereas the time

that the asphalt spends therein depends upon the distance that it must fall within the vessel, i.e., upon the height of the vessel. The ratio of height to diameter of all of the reaction chambers employed by Standard Oil Company of California is within the range of approximately 6:1 to 8:1. This range is too small for the shape factor to be perceptible in results obtained from the cracking unit. However, chambers of markedly different relative dimensions may give results appreciably different from those presented herein.

It is realized that use of the correlation factor $V/R$ leaves much to be desired. However, the results obtained by its use were sufficiently accurate for solution of the engineering process, and economic problems involved; and the laborious calculations based upon a sounder theoretical background could not be justified.

### Heat Requirement

Figure 2 is a graph showing the effect of reaction chambers on the net heat requirement of cracking heavy California residuums in equipment similar to that shown in Figure 1. This graph is based on raw feed entering the unit at 60° F., with no indirect heat exchange employed in the unit, and no naphtha recirculation to the top of the fractionating column. Figure 2 is based on a large number of experimental and commercial data, and is believed to be quite accurate.

As an example of the reduction in heat requirement obtained in commercial practice, Standard Oil Company of California installed 8-foot x 50-foot reaction chambers on 4 units, each with a daily feed capacity of approximately 8000 barrels. The units were designed essentially as shown in Figure 1. Installation of the chambers increased the $V/R$ from about 50 to about 300. Test data showed that the heat requirement was decreased about 17 percent, which is in close agreement with the graph shown in Figure 2.

The following tabulation indicates the heat requirement before and after installation of the chambers:

| | Without Chamber | With Chamber | Decrease (Percent) |
|---|---|---|---|
| | (Btu Per Barrel of Raw Feed) | | |
| Heat differential: 60° to raw-feed temperature of 140° F. | 14,000 | 14,000 | .. |
| Absorbed in raw-feed-naphtha heat exchanger | 20,000 | 17,000 | .. |
| Absorbed in furnace | 166,000 | 135,000 | 19 |
| Total requirement above 60° F. | 200,000 | 166,000 | 17 |

This particular installation saved about 31,000 Btu in furnace-heat absorption per barrel of raw feed, which, at 70 percent furnace efficiency, corresponds to a saving of about 7 barrels of fuel per 1000 barrels of cracking stock processed.

### Capacity of Unit

It has been the experience of Standard Oil Company of California that the maximum annual through-put and the minimum operating and maintenance cost per barrel of gasoline are obtained if the cracking plant is operated at a high feed rate, such that tube coking necessitates shutdowns for cleaning after runs of about 700 hours. The rate of tube coking in a given furnace is dependent upon the total heat absorption therein; hence, a reaction chamber increases the capacity of a given cracking unit due to the decrease in the required heat absorption per barrel charged.

In addition to the above factor, a reaction chamber transfers the more severely coke-forming part of the cracking reaction to a point outside of the furnace tubes. This permits a given furnace to absorb more heat per hour, for a given rate of coke deposition, if a unit with a reaction chamber is used than if no chamber is employed. This factor permits a greater increase in the raw-feed rate to be made when a chamber is installed than would be anticipated on the basis of the decrease in heat requirement alone.

Figure 3 shows the percentage increase in daily feed capacity obtained in the different Standard Oil Company of California plants when reaction chambers were installed. This chart corresponds to production of a given yield of cracked naphtha of a given gasoline content. The gasoline content of the naphtha assumed in preparing this chart was 80 percent, which is a value readily obtainable on units either with or without reaction chambers.

In the example cited previously, viz., installation of an 8-foot by 50-foot chamber on an 8000-barrel-per-day unit, $V/R$ was increased from 50 to 300, and the raw-feed capacity was increased 27 percent (up to 10,200 barrels per day) for operation at constant naphtha yield and gasoline content. This corresponds to an increase of 27 percent in the daily gasoline-producing capacity of the unit. These results are in accord with the graph shown in Figure 3.

When heavy California residuum is charged, a unit similar to that shown in Figure 1 makes its

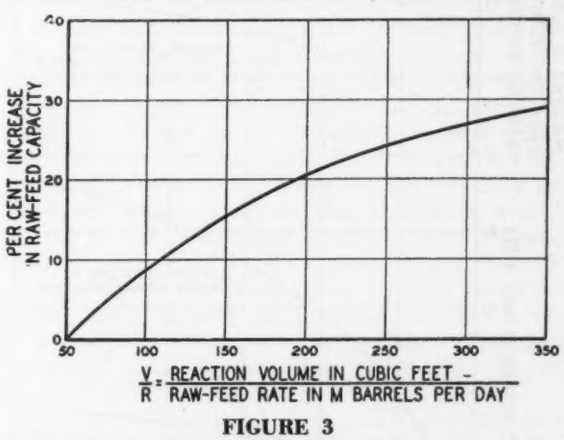


**FIGURE 3**

**Effect of reaction volume on raw-feed capacity of a cracking unit—operation at constant naphtha yield and constant gasoline content of naphtha.**

maximum daily gasoline production at approximately 80 percent gasoline content in naphtha (400° F.-end-point gasoline) with $V/R$=50 (without reaction chamber), and at approximately 100 percent gasoline content with $V/R$=300 (with chamber). The attempt to produce more volatile naphthas than these—whether by an increase in the production of the mixed feed going to the upper part of the vapor column or by the recirculation of naphtha to the top of the column—always results in a marked decrease in the gasoline-production rate. Use of a reaction chamber is, therefore, an economical means both of increasing the gasoline content of naphtha and raising the gasoline yield.

Figure 4 shows the changes in plant capacity that occur when a reaction chamber is added, provided the unit is operated in all cases with the gasoline content of the naphtha such that the maximum daily

production of gasoline will result. The increase in feed rate obtained under these conditions is less than what would be obtained if naphtha of a fixed lower gasoline content were made; however, this penalty is offset by a greater increase in the daily gasoline production from the unit.

In the example cited previously, i.e., in which an 8-foot x 50-foot vessel was added to an 8000-barrel-per-day unit, the feed rate would be increased 16 percent, or to 9300 barrels per day; the gasoline content of the naphtha would be increased from 80 to 100 percent; and the daily production of gasoline would increase 45 percent, as compared with an increase of only 27 percent if the naphtha quality were maintained constant.

The refinery demand for light gas-oil cutter stock determines which of the above alternatives will be used in any given case to realize the advantages resulting from installation of reaction chambers. In many cases the most advantageous results may be obtained at some intermediate point.

### Quality of Cracked Products

Use of reaction chambers decreases the severity of cracking of the heavy asphalt constituents of the charging stock. This means that the asphalt is less severely viscosity-broken, and the viscosity of the cracked residuum for a given naphtha yield is increased. A charging stock with a Saybolt Universal viscosity of 800 seconds at 130° F., if cracked to yield 35 percent naphtha in a unit of 50 $V/R$, produces a cracked residuum with a Furol viscosity of approximately 400 seconds at 122° F.; whereas in a unit of 300 $V/R$ the Furol viscosity of the residuum is about 580 seconds at 122° F. for the same naphtha yield.

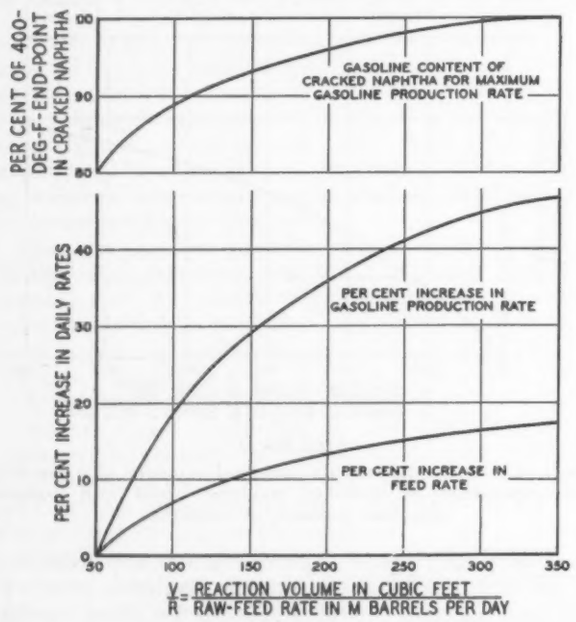


**FIGURE 4**

**Effect of reaction volume on feed rate, gasoline content of cracked naphtha, and cracked-gasoline producing capacity of a cracking unit—based on operation for maximum gasoline production.**

California refiners often encounter some difficulty in meeting the viscosity specification of the different cracked fuels sold, due to the high percentage of heavy ends in most California crude oils. The decrease in degree of viscosity-breaking is, therefore, an undesirable factor in the use of reaction chambers; however, this usually can be offset by other feasible changes in the refinery stock balance. This problem would not exist in refineries processing lighter crude oils.

Use of reaction chambers also appreciably decreases the sediment content of the cracked residuum produced at a given yield of cracked naphtha. This effect is probably due to the decrease in severity of cracking of the asphalt component of the charging stock.

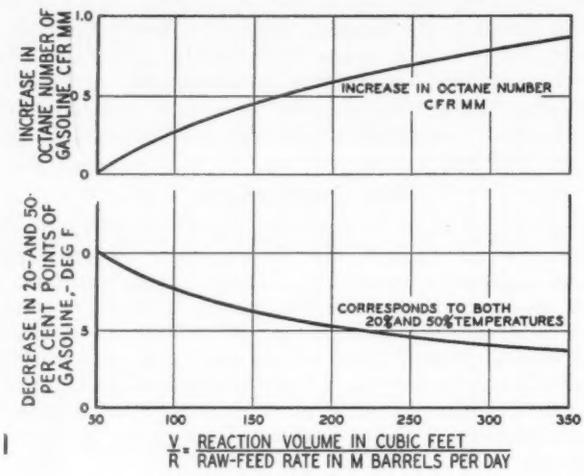


**FIGURE 5**

**Effect of reaction volume on octane number and volatility of gasoline of constant end point and vapor pressure.**

Cracking units equipped with reaction chambers produce gasoline of higher volatility than do units without chambers. The spread between the 50- and 90-percent points is increased, the spread between the 20- and 50-percent points remaining essentially unchanged. The magnitude of this effect is shown in Figure 5. For example, installing an 8-foot x 50-foot chamber on an 8000-barrel-per-day unit lowered the 20- and 50-percent points of gasoline of a given 90-percent point by about 6° F.

Chambers also increase the octane number of the cracked gasoline, due in part, to the increase in volatility and, in part, to change in chemical character of the gasoline. As shown in Figure 5, installation of an 8-foot x 50-foot chamber on an 8000-barrel-per-day unit raised the CRF motor-method octane number of gasoline of a given 90-percent point by 0.8.

In none of the tests performed by Standard Oil Company of California was it found that the use of reaction chambers caused any detectable change in the sulfur content, amount of acid required for finishing, or in the lead susceptibility of the cracked gasoline.

### Improvement in Plant Operation

A reaction vessel serves as a surge chamber to absorb fluctuations in the operation of the cracking unit. A unit equipped with a reaction chamber is substantially easier to operate and control than a unit not so equipped. Abrupt variations in feed quality or in top transfer temperature are less likely to coke the tubes, because the coke-forming part of the reaction occurs primarily in the chamber. Uncontrollable "swings" in the operation are also substantially less likely to occur.

It is, therefore, possible to operate a unit with a chamber substantially closer to its maximum theo-

retical capacity than a unit without a chamber. Shutdowns for cleaning because of coke which formed during accidental "swings" are less frequent. Standard Oil Company records show that the installation of chambers improved the equivalent operating factor of the unit about 5 percent for the foregoing reasons. This improvement in operating factor resulted in a 5-percent increase in the annual plant throughput over and above the increase in maximum theoretical capacity shown in Figures 3 and 4.

### Economics of Reaction Chambers

Use of reaction chambers effects an appreciable saving in the unit manufacturing cost of the gasoline. The unit labor cost is reduced, because the plant capacity is increased without increase in the number of men required to operate the plant. The fuel cost is decreased, because the net heat requirement of cracking is reduced, and because the furnace usually can be operated at higher efficiency. A small saving in cooling water is made, because the products leave the unit at lower temperature.

Standard Oil Company of California experience has been that the annual maintenance cost for a given unit is essentially the same whether a chamber is employed or not. Hence, the maintenance cost per barrel of gasoline is decreased approximately in proportion to the increase in plant capacity.

The increase in octane number of the cracked gasoline can be utilized either by a decrease in the amount of tetraethyl lead, or by diversion to some other gasoline—in which their value may be greater—of other high-octane stocks used in the final gasoline blend. The increase in volatility of the cracked gasoline may be utilized by a decrease in the volume of natural gasoline employed in the refinery, or by other readjustments in the refinery stock balance.

Use of chambers decreases the degree of viscosity-breaking obtained in the unit, but it is difficult to evaluate financially the penalty that may result from such decrease in viscosity-breaking. No penalty would exist in refineries that process light crudes. In refineries that process heavy crudes and that are short of light gas oils, detailed analysis of the entire refinery stock balance is required to find means of offsetting the decrease in viscosity-breaking resulting from use of chambers.

In analyzing the economy of installing reaction chambers on new or existing cracking units, study must be made to ascertain if the advantages of these chambers are truly realizable in the particular refinery stock situation in question. For example, if the chambers were to be installed on existing units, and if no increase were required in the daily cracked-gasoline production in the refinery, it is possible that little saving in unit operating cost would be made, unless one or more of the units could be shut down as a result of the increased capacity of the others. Similarly, little credit could be taken for improved volatility of the cracked gasoline unless it were possible to decrease the refinery input of natural gasoline.

In all of the installations of reaction chambers made by Standard Oil Company of California, it was found possible to take full advantage of all of their favorable effects described hereinbefore. Other means were found to offset the disadvantage of reduced viscosity-breaking.

When a refinery stock situation reaches the point where increase in the cracked-gasoline production is required, decision on the following factors is necessary:

1. Should a new cracking unit of the existing type be built.
2. Should the new unit include a reaction chamber.
3. Should reaction chambers be installed on existing cracking units.
4. What is the economical size of the reaction chambers to be installed.

Usually these questions resolve themselves into finding the cheapest way of obtaining the required additional capacity. If the required increase in gasoline production is within the range of that attainable by the installation of reaction chambers on existing units, it is believed that this alternative is far cheaper than to build new units.

If, for example, an 8-foot x 50-foot vessel, costing perhaps $60,000, were installed on an existing 8000-barrel-per-day unit, the daily gasoline production therefrom would be raised from about 2300 barrels to about 2900 barrels, or an increase of about 600 barrels per day (27 percent), for constant naphtha yield and quality. The additional gasoline, therefore, would be obtained from an investment of only about $100 per barrel per day, as compared to about $225 for construction of a new unit of the type shown in Figure 1.

Construction of new units, of course, would be required if the necessary increase in gasoline production were larger than that attainable by the installation of reaction chambers on all existing units. Even in this case, however, consideration should be given to the attainment of at least part of the required increase in capacity by installation of chambers.

Analysis of each particular situation is required to determine the most economical size of reaction chamber to install on either the new or the existing units. If economic analysis shows that chambers would be desirable, it is believed that in most cases the vessels should be relatively large; i.e., of such size that a $V/R$ of at least 300 to 400 is obtained. In the case of small cracking units it may be desirable to use a vessel giving a $V/R$ substantially larger than this, as the incremental cost of obtaining the higher value of $V/R$ may be relatively small.

As shown in Figures 2, 3, 4, and 5, increase in size of reaction chambers is subject to diminishing return; however, up to the point of employing the largest vessels readily obtainable, the incremental cost of the large vessels as compared to the small ones is relatively small.

Many cracking units in this country are equipped with reaction chambers that correspond to a $V/R$ of 100 to 200. It is believed that in many cases it would be worthwhile to give consideration to the replacement of the existing chamber by another larger vessel, or to the installation of another vessel in parallel.

### Conclusion

During recent years Standard Oil Company of California has installed auxiliary downflow reaction chambers on most of its cracking units in service. Use of the chambers has resulted in increased plant capacity, improved product quality, and reduced cost. It is believed therefore, that installation of additional reaction chambers on many of the cracking units in use in this country would be advantageous.

# Naphtha Treating "Pays Its Way"

C. F. MASON, R. D. BENT and J. H. McCULLOUGH
The Atlantic Refining Company

**THE caustic-methanol process removes essentially all mercaptans from sour gasolines by extracting them with only 2 percent of strong caustic and a suitable quantity of methanol. The spent reagent is regenerated by steam-stripping and fractionation, and can be used indefinitely for mercaptan extraction.**

**The paper presents pilot-plant studies of the extraction and regeneration steps. Data are given on reagent losses, utility consumption, control of the stability characteristics of the finished gasoline, and improvement in octane number and lead susceptibility over the untreated gasoline. The increase in leaded octane numbers of the treated products usually will offer an attractive saving in lead additions.**

**The process is ready for full-scale application. Several large plants are under way.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 6, 1941.**

IN SPITE of the rapid and widespread "face lifting" which has taken place in refinery processing methods in the last decade, the naphtha-treating plant has undergone little basic change by the onslaught of new techniques, and in many plants, stands as an expensive citadel which successfully has resisted all development efforts. It is true that various schemes of regenerative caustic washing have eased the treating-cost burden in many places, but these have been only partial answers to the problem; and mercaptan conversion, by doctor treating or otherwise, continues as the predominating means of improving odor. Simultaneously, this same processing is harming both octane value and susceptibility to tetraethyl lead.

These deleterious effects of mercaptan conversion have been known for several years, and upon this realization came the pat and obvious answer—mercaptan removal. That much was easy, but how to do it was something else again. The mercaptans in the heavier parts of gasoline have objectionable odors, but are not sufficiently soluble in a cheap reagent such as aqueous caustic soda. Organic solvents, either alone or in caustic-soda solution, tend to be excessively expensive, particularly if appreciable quantities are lost in the treated naphtha. Further, any solvent which removes mercaptans, of necessity, gradually will become fouled with sulfides, sulfates, thiosulphates, phenols, thiophenols, fatty acids, etc., unless some mechanism is provided for discharging these materials from the recirculation system without incurring excessive cost of reagent loss. This looks like a large order to expect any process to fill, but gasoline is a large-volume product of the refinery, and fractional unit savings in tetraethyl lead and octane level expand to large annual dollar returns and furnish incentive for extensive research and development work.

The caustic-methanol process, a development of The Atlantic Refining Company, meets the requirements imposed by the mercaptan-removal problem in an unusually satisfactory manner and, in addition, the commercialization of the process has disclosed that the unit manufacturing costs are considerably lower than had been anticipated at the beginning of the development. This gratifying fact increases the economic incentive for the installation of the process, and has resulted in large plant installations being pushed with all possible expedition.

### Research Background

The caustic-methanol process was conceived some years ago, but was not commercialized at that time because of the lack of the large dollar driving force which has become apparent recently. The process in developed form has a research background of extensive studies of physical and chemical properties involving naphthas, mercaptans, solvents, and phenolic contaminants, alone and in mixture with aqueous caustic soda of various concentrations. The end product of this investigation is the result of economic evaluation of such factors as low cost of solvent components, low loss in treated naphtha, high solubility for mercaptans resulting in low recirculation rates, ease of separation of solvent components to permit ready control of recycle contamination, and overall flexibility with regard to sources and types of naphthas which can be handled.

All of these data and studies will appear in the literature as occasion warrants. They have no place in the present discussion, as our object here is to examine the commercialized process which is the outcome of many months of operation of a semi-commercial plant on a variety of refinery naphthas at rates up to 300 barrels per day.

### The Semi-Commercial Unit

Upon reaching a decision that the research laboratory really had the germ of a good mercaptan-removal process in the caustic-methanol combination, the semi-plant unit was erected in the naphtha-

treating area of the refinery to permit ready access to large volumes of a variety of charging stocks. The nominal capacity of this plant was 50 barrels per day, but in operation the rate has been varied from 15 to 300 barrels per day in the course of pursuing the acquisition of data for use in full-scale design.

A simplified flow diagram of the plant is given in Figure 1. Sour gasoline, essentially free of hydrogen

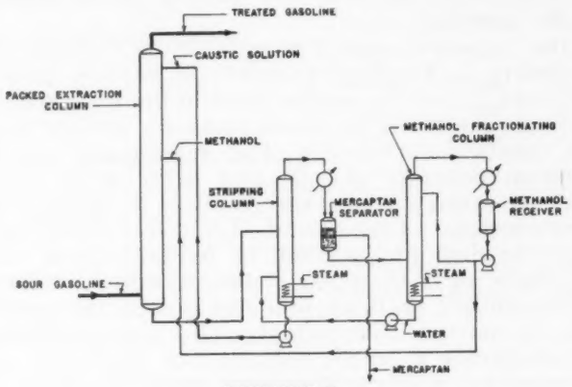


**FIGURE 1**
**Simplified flow diagram of the semi-commercial caustic-methanol unit.**

sulfide, flows upward through a countercurrent extraction tower, packed with raschig rings. Regenerated caustic-soda solution is pumped to the top of the tower and, in flowing down through the upper section, removes practically all of the methanol from the demercaptanized gasoline. Lower in the column, the methanol is introduced, and the combined solvents extract the mercaptans from the gasoline.

The spent reagent from the bottom of the extraction tower is pumped to a steam-stripping tower of conventional design. From the bottom of this tower, regenerated caustic is withdrawn and recycled to the top of the extraction tower. The overhead from the stripper—a mixture of methanol, mercaptans, and steam—is condensed, and the condensate separates into two layers in the receiver. The mercaptans collect in the upper layer, and are withdrawn from the system at this point. The lower layer is a water-methanol mixture maintained low in mercaptan content by controlling the water-methanol ratio to give minimum mercaptan solubility.

The water-methanol mixture drawn from the bottom of the mercaptan separator is charged to the methanol fractionator. The methanol taken overhead is recycled to the middle section of the extractor. The water residuum from the fractionator recycles to the caustic stripper. Figure 2 gives a general idea of the size and scale of the semi-commercial plant under discussion.

### Semi-Commercial Operation

Inasmuch as the objectives of the semi-commercial operation were twofold—obtaining data for full-scale plant design, and obtaining operating costs and results on a variety of naphthas for economic justification—two distinct types of operation appeared in the program.

In one type of operation, four contact towers having cross-sectional areas of around 20, 27, 48, and 108 square inches were run to obtain extraction-tower-capacity data as well as to permit wide variations in the regenerator-section loads. In addition, packing size was varied to establish the optimum combination of tower size and packing size for any required design capacity. Similar basic design data have been established for the regeneration equipment. In the course of this phase of the program, an automatic control system applicable to plant design was successfully developed.

In the work which obtained data for economic justification of the process, more than 250 runs were made under a variety of conditions on numerous types of gasolines. Table 1 is illustrative of the type of information obtained. This particular one is a Gray processed cracked gasoline. It is noteworthy that this gasoline has a full boiling range (end point, 422° F.), and yet the high capacity of the caustic-methanol reagent permitted excellent mercaptan removal with a recirculation rate of only 2.8 percent by volume of total solvent based on the charge naphtha. For this reason, the regeneration equipment is small and relatively inexpensive, and steam and utility consumptions are low. This high mercaptan-carrying power of the caustic-methanol reagent is emphasized further when it is realized that the extraction side of the plant was operating at the normal treating temperature of 100° F.

A study of reagent loss is pertinent and illuminat-

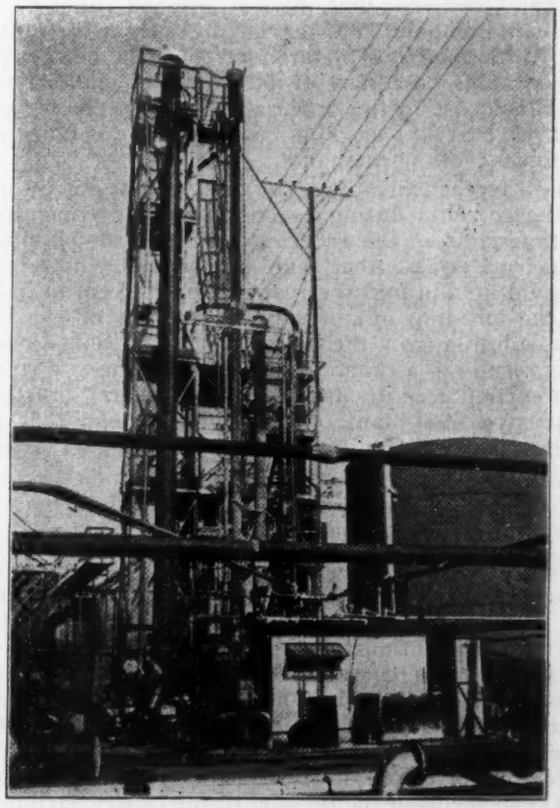

**FIGURE 2**
**The semi-commercial unit.**

ing, in that it throws into bold relief a feature of the caustic-methanol process which is outstanding. This feature is the separation of the two components of the reagent and the return of them separately to the system. In addition to other flexibility features which will be mentioned later, charging the regenerated caustic-soda solution to the top of the extractor tower causes this section to function admirably as a

**TABLE 1**
**Semi-plant Extraction of Gray Treated Cracked Gasoline**

| | | |
|---|---|---|
| Operating Conditions: | | |
| Gasoline throughput | 90 | gal per hour |
| Regenerated caustic | 2.0 | per cent by volume |
| Recovered methanol | 0.8 | percent by volume |
| Treating temperature | 100 | °F |
| Charge inspection: | | |
| Gravity, deg API | 58.1 | |
| **ASTM distillation, in °F** | | |
| Initial boiling point | 98 | |
| 10-percent point | 146 | |
| 50-percent point | 248 | |
| 90-percent point | 372 | |
| End point | 422 | |
| Reid vapor pressure, lb. | 7 | |

| Comparison of Quality | Sour Gasoline | Treated Gasoline |
|---|---|---|
| Total sulfur, percent by weight | 0.110 | 0.067 |
| Mercaptan sulfur, percent by weight | 0.043 | 0.0005 |
| Methanol, percent by weight | .... | 0.004 |
| Color (Saybolt) | 24 | 25 |
| ASTM Octane No.: | | |
| Clear | 71.9 | 71.9 |
| Plus 1 ml TEL* | 76.4 | 77.9 |
| Plus 2 ml TEL | 78.7 | 80.2 |
| Plus 3 ml TEL | 80.3 | 81.8 |
| Induction period, hours:† | | |
| Clear | 8.25 | 4.50 |
| Plus recovered phenol | .... | 8 |
| Plus 0.0025 percent by weight of UOP No. 4 inhibitor | .... | 8.50 |

*Tetraethyl lead.
†ASTM tentative "gum stability of gasoline."

methanol-recovery unit. As a result, the outlet gasoline contains only 0.004 percent by weight of methanol. With methanol debited at 35 cents per gallon and gasoline credited at 5 cents per gallon, the methanol cost to the process is of the order of 0.05 cent per barrel of gasoline treated. There is no other significant loss of methanol.

As a further advantage accruing to the separation of the solvents during regeneration, the control of contaminants in the recycled reagents can be cited. Acidic materials, other than mercaptans, which tend to build up and foul the reagent can be kept in hand by the bleeding out of small quantities of caustic-soda solution from the bottom of the stripper tower. This results in a caustic-soda consumption similar to that encountered in current caustic washing practice. Extensive semi-plant operation has shown that no foreign materials build up in the methanol and, hence, the methanol can be used indefinitely.

## Plant-Equipment Considerations

In translating the knowledge gained from the semi-plant experiences to full-plant design, several items are noteworthy. The extraction tower is a packed tower of conventional design; the various towers and drums on the regeneration side are equally unexciting from the design angle when the fundamental data pertinent to the process are at hand to work with. The moderate temperatures and pressures avoid the necessity for use of alloy steels, except for the tubes and tube sheets of the reboiler of the caustic-stripping tower. Here, the materials commonly used by the chemical industry for handling boiling caustic-soda solutions are indicated. These materials are nickel, nickel-clad steel, monel, special cast irons, etc. An interesting item in connection with the corrosion angle of the process is one which is indicative of the type of specialized knowledge obtained in the course of major developments, and which are always a valuable part of operating "know how." This is the indication that a buildup of sodium-sulfide concentration in the reagent increases corrosion rates. Thus, it is recommended that hydrogen-sulfide-free gasolines be treated, usually a simple matter to take care of in the refinery, using existing equipment.

## Control of Gasoline-Stability Characteristics

Experience with a number of solvents teaches that any solution capable of extracting mercaptans also will extract, to some degree, any phenolic bodies present in the gasoline and, as a result, there will be a reduction in the oxidation-stability characteristics of the gasoline.

The caustic-methanol process offers considerable flexibility in handling gasolines of varying phenol contents. It will be recalled that, in the regeneration step, the methanol and mercaptans are distilled from the caustic-soda solution. This regenerated caustic solution contains phenols and other acidic components extracted from the gasoline. If the stability characteristics of the gasoline being treated are such that the final product will be better because substantially all of the acidic bodies have been removed and because a synthetic inhibitor is used, the process can be controlled accordingly. This is accomplished by discarding a caustic solution rich in phenols (50 percent by weight). The high ratio of phenol to caustic in this type of operation results in a low consumption of caustic soda.

If, on the other hand, the nature of the gasoline being treated permits the advantageous retention of the phenols, the process can be controlled to favor this retention. This is accomplished by permitting the phenols to build up in the recycled caustic-soda solution. The carrying power of the reagent for mercaptans is not impaired by this buildup of phenolates, but the extraction of phenols from the gasoline notably is depressed.

In all cases, the susceptibility of the caustic-methanol–extracted gasolines to the action of synthetic oxidation inhibitors is excellent. In addition, the major portion of those phenols which are extracted is recovered *as phenols* from the methanol fractionation in the regeneration system at no additional operating cost. The return of these recovered phenols to the treated gasoline will reduce the synthetic-inhibitor requirements. In this connection, it is of interest to note that, in the case of the gasoline treated and reported in Table 1, the recovered phenols alone were able to restore the induction period to substantially its original value.

## Economic Considerations

Table 2 tabulates the results of the semi-plant treatment of a variety of different gasolines. In all these cases, the same volume percent of recirculation of reagent (2.8 percent) and treating temperature (100° F.) were used, and uniformly good mercaptan removal resulted. Clear octane numbers of the treated products were equal to or better than those of the sour stocks, which is noteworthy in view of the 0.25 to 1.0 number loss commonly encountered when the mercaptans are converted rather than extracted. Further, the increased susceptibility to tetraethyl lead offers an attractive lead saving in all cases.

The economics which require consideration for the evaluation of the caustic-methanol process in comparison to mercaptan-conversion processes are relatively simple. If, to the items mentioned previously, is added the fact that with the low reagent recirculation there is required only 10 pounds of steam per barrel of gasoline to accomplish reagent regeneration,

**TABLE 2**
**Semi-plant—Results on Various Gasoline Stocks**

| Gasoline Stock | | Boiling Range (°F) | Total Sulfur (Percent by Weight) | Mercaptan Sulfur (Percent by Weight) | Mercaptan Removal (Percent) | ASTM Octane No. Clear | Plus 1 Ml TEL | Plus 2 Ml TEL | Plus 3 Ml TEL | Reid Vapor Pressure (Pounds) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Blend of polymer and high-sulfur cracked gasolines | Charge | 96–390 | 0.190 | 0.0615 | 98.9 | 74.0 | 78.0 | 80.5 | 81.5 | 8.0 |
| | Product | 96–390 | 0.128 | 0.0007 | | 74.0 | 80.0 | 82.2 | 83.8 | 7.5 |
| 2. †High-sulfur cracked gasoline | Charge | 104–464 | 0.248 | 0.045 | 98.9 | 68.6 | 72.8 | 74.9 | 76.0 | 6.0 |
| | Product | 104–464 | 0.182 | 0.0005 | | 68.8 | 73.6 | 75.9 | 76.9 | 5.7 |
| 3. Low-sulfur cracked gasoline | Charge | 100–420 | 0.076 | 0.031 | 98.7 | 70.0 | 74.9 | 77.6 | 79.3 | 8.0 |
| | Product | 100–420 | 0.036 | 0.0004 | | 70.2 | 76.6 | 78.9 | 81.1 | 8.0 |
| 4. †West Texas straight-run gasoline | Charge | 85–290 | 0.076 | 0.035 | 98.9 | 69.2 | 75.4 | 79.4 | .... | 17.4 |
| | Product | 85–290 | 0.041 | 0.0004 | | 70.6 | 77.2 | 80.9 | .... | 17.4 |
| 5. West Texas straight-run gasoline | Charge | 90–345 | 0.119 | 0.062 | 98.9 | 68.5 | 75.2 | 78.0 | .... | 14.1 |
| | Product | 90–345 | 0.056 | 0.0007 | | 72.0 | 77.5 | 81.3 | .... | 14.0 |
| 6. Mixed straight-run gasolines | Charge | 120–360 | 0.056 | 0.008 | 96.3 | 62.5 | 70.1 | 74.7 | 78.2 | 5.0 |
| | Product | 120–360 | 0.049 | 0.0003 | | 64.2 | 72.1 | 77.8 | 80.5 | 4.9 |
| 7. *High-vapor-pressure blending stock | Charge | .... | .... | 0.1300 | 99.6 | 62.0 | 70.1 | 73.6 | .... | .... |
| | Product | .... | .... | 0.0005 | | 62.0 | 72.6 | 78.0 | .... | .... |

*The charge stock in "7" was a 35-lb-Reid-vapor-pressure stock.
Octane numbers were obtained on blends of 25 percent of this material in 75 percent of low-sulfur mercaptan-free straight-run gasoline of the following inspection:
ASTM octane No.:
Clear.....50.2
Plus 1 ml TEL.....63.2
Plus 2 ml TEL.....69.5
†The gasoline charge to these runs is a caustic-washed product; mercaptans partly removed.
**Note:** All runs are same percent by volume of "treat" and same operating temperature as in Table 1.

it is not a burdensome task to add also reasonable figures for power, water, labor, etc. If this is done, a manufacturing cost of approximately 1.0 cent per barrel of naphtha, including reagent loss, is reached. From the standpoint of lead susceptibility and octane number, the previously mentioned data show that, in the average application, at least 0.25 ml of tetraethyl lead per gallon of gasoline can be taken as a credit and, in many cases, a considerably higher figure will be obtained.

From the plant-investment cost angle, precise figures are difficult to give, due to variations arising as a result of differences in capacities and local conditions. It is believed that, for a plant of reasonable size—say 5000 barrels per day—the investment will range from $8 to $12 per barrel per day.

### What Price the Doctor Test?

The doctor test was originated to measure the completeness of the conversion of mercaptans to disulfides as carried out by the doctor-sweetening process. It always has been a test difficult to interpret, and border-line cases have caused almost endless bickering. It will be noted that doctor-test results in this discussion are conspicuously absent, and intentionally so.

The caustic-methanol process can produce gasoline "sweet to doctor," but it is pertinent to point out just how silly it would be to dwell on this ability. At various times during the experimental program the product from the caustic-methanol plant has run slightly "off doctor" for long periods of time, and yet the actual mercaptan content of the gasoline was lower than the "OK doctor" product from the doctor-treating plant running on the same stock and alongside of it! An interesting side comment is that certain critical noses in the organization express a preference for the odor of the "extracted" to the "converted" product—so that, apparently, the disulfides are not as odorless as we have grown to believe.

The caustic-methanol process is offered for your consideration as a mercaptan-removal process furnishing all the benefits that accrue from substantially complete removal of mercaptans from gasoline. Although the "doctor" can be met, we insist on gauging the efficiency of mercaptan removal by measuring the residual mercaptan in the treated gasoline.

### Acknowledgment

Acknowledgment gratefully is made to the technical personnel of the Universal Oil Products Company of Chicago, Illinois, for assistance in the preparation of this discussion. This company is the licensing agent for the process under U. S. patents No. 1,968,842, 1,968,843, and 2,043,254, and pending applications.

# Improved Motor Fuels Through Selective Blending

C. R. WAGNER, W. B. ROSS, L. M. HENDERSON, The Pure Oil Company
and
T. H. RISK, Ethyl Gasoline Corporation

**THIS paper is a report of the progress that has been made in a program begun in 1938 to investigate the effect of the chemical composition of fuels on the road anti-knock performance and road lead susceptibility of these fuels. The data presented are based on the results of road tests of some 284 special fuel blends and approximately 200 commercial gasolines in 25 different cars. The borderline road-knock testing method was used throughout these tests, as it seemed best adapted to a study of fuels in accordance with the arbitrary definition of the "ideal" fuel set up at the start of the investigation. As defined for the purpose of these tests, an "ideal" fuel is one which will satisfy the anti-knock requirements of any engine in which it is used throughout the engine-speed range, but which will not possess any "wasted" or excessive anti-knock quality at any car speed. The results obtained to date indicate that the fuel which most nearly will satisfy this definition of the "ideal" fuel is one in which the light fractions are composed primarily of olefinic material and the heavy fractions are composed primarily of paraffinic material. Several ways of utilizing this information in the commercial production of motor fuels are suggested.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 7, 1941.**

MOST motor fuels today are blends of various refinery stocks and tetraethyl lead, the exact composition of which is governed primarily by the necessity of blending to a definite laboratory octane value. It is a familiar fact, however, that two fuels of the same laboratory octane value very often differ markedly in their road anti-knock performance. This may be due in large part to the fact that standard methods of knock testing do not reveal the effect of chemical composition of fuels upon the road anti-knock behavior and the road lead susceptibility of these fuels.

Many research laboratories have devoted a large amount of time and effort to the clarification of the discrepancies that exist between road and laboratory knock ratings and the reason for these discrepancies. It was during experimental work along these lines that the authors were impressed with the possibility that the chemical composition of a gasoline could be modifed so as to secure, within reasonable limits, any desired road anti-knock performance without changing the motor-method octane level of the fuel. This paper is actually a report of the progress that has been made in this investigation. It is obvious that a complete survey of this subject is entirely beyond the scope of any single laboratory. It is hoped that the information given herein will stimulate interest in this problem which, in turn, will result in the production of better fuels for the future.

Before proceeding with an extended investigation of the effect of chemical composition on the road anti-knock performance of fuels, it seemed advisable to set up arbitrarily a definition of the "ideal" fuel, based on road behavior, in order to have some means for evaluating the characteristics of experimental fuel compositions that might be tested. Naturally, the definition of such an "ideal" fuel cannot be static, but must vary both with the requirements of existing and projected engines and with individual ideas of fuel behavior. For the purposes of this paper, the authors define an "ideal" fuel as one which will satisfy the anti-knock requirements of any engine in which is may be used, throughout the entire speed range, but which will not have excessive anti-knock value at any speed. (The authors recognize, of course, that it may be more economic to produce a fuel having "excessive" anti-knock value in some part of the speed range than to produce the "ideal" fuel. From the technical standpoint, all fuels which satisfy completely the anti-knock requirements of a given car will be equally satisfactory in that particular car). The road-knock test procedure suggested by Hebl and Rendel [1] in 1937 and further amplified by Drinkard and Macauley [2] in 1938 is particularly well adapted to the testing of fuels in accordance with this definition. This test procedure, known as the borderline road-knock testing method, has been published in the *SAE Journal*, [3] and is described briefly further on in this paper in a manner more suited to the present discussion.

The experimental work on which this paper is based was begun in 1938, and has been continuously in progress since that time. Altogether, some 284 special fuel blends and aproximately 200 commercial motor fuels have been investigated in 25 different cars. It is impossible to present all of these data in a paper of this kind; and we have, therefore, selected those which seem to be most representative of the general indications of our investigations.* This test work can be divided logically into four parts:

Part 1. A survey of commercial gasolines to determine whether they satisfied the definition of an "ideal" fuel, and a cursory investigation of methods which might be employed to improve these fuels.

Part 2. A study of the road anti-knock performance of special blends which possibly may be used as motor fuels of the future, and the ability of such fuels to respond satisfactorily to additions of tetraethyl lead.

Part 3. A study of the economic possibilities of manufacturing any of the improved fuels which the

* Complete road-test data for the fuels given in Tables 2 and 3 are available on request to American Petroleum Institute, 50 W. 50th Street, New York.

investigations under (1) and (2) have indicated to be desirable from a purely technical point of view.

Part 4. The possibility of evaluating fuels, and of correlating road with laboratory results, as indicated by the fuels tested in these experiments.

We believe that sufficient work has been done under Part 1 of these studies to assure us that desirable changes can be made in the road anti-knock performance of fuels by altering their chemical composition. Certainly, the results are promising enough to warrant further intensive work along this line. Although a considerable amount of work has been done on Part 2, the surface has only been scratched, but already many possibilities for producing improved motor fuels have been indicated. The data reported under Part 3 are only the first efforts to determine how practical the production of fuels selectively blended in accordance with these studies may be. Additional work on this problem is now in progress in an attempt to determine whether the apparent cost of manufacture of these special fuels can be justified. Too little work has been done under Part 4 to permit a definite statement to be made, but the data do not indicate any significant correlation between road performance and the "motor" and "research" octane numbers of the fuels tested.

### Borderline-Knock Test Method

All of the road test work on which this paper is based was done by the borderline-knock test method, as this procedure seems best to indicate the extent to which a given fuel meets the arbitrary definition of the "ideal" fuel. A borderline curve gives a graphic idea of a fuel's ability to tolerate spark advance throughout the engine-speed range. As its name implies, it represents the knock-die-out point between satisfactory and unsatisfactory operation, i.e., between non-knocking and knocking operation.

In conducting tests by the borderline method, a certain amount of special equipment is necessary. Of primary importance is a fixed distributor, i.e., one which will not advance the spark with engine speed, as is the case with all standard distributors. There must be a satisfactory means for adjusting the spark from the driver's seat. Likewise, there must be a suitable means for determining the spark advance while the engine is being operated on the road; an electronic or stroboscopic indicator is satisfactory for this purpose. There also should be a tachometer, conveniently located, because engine "revolutions per minute" rather than car "miles per hour" usually is used to indicate speed.

With the special equipment conveniently installed in the test car, the procedure for determining the borderline curve for a fuel is as follows: The car first is operated for a sufficient length of time to insure that the test fuel has displaced completely the original tank fuel in the fuel system. Then, the spark is set manually to a relatively low advance, usually 2 to 6° before top dead center. The car is slowed down to as low a speed as possible in high gear, generally about 6 mph to 8 mph, and then accelerated with wide-open throttle; the speed at which the knock dies out is noted. This gives one point on the borderline curve—representing the two dimensions, spark advance and knock-die-out speed. The spark then is advanced 2°, and the entire procedure repeated to give the second point on the curve. This process is continued until the complete curve has been established for the spark-advance and engine-speed range under consideration. Care must be taken to prevent excessive knocking, as the knock-die-out point is of primary importance.

Borderline test data usually are plotted as shown in Figure 1. The light dotted line and the dot-dash line represent, respectively, the distributor-advance

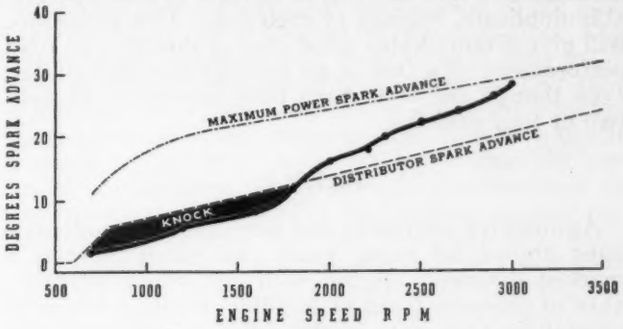


**FIGURE 1**

**Borderline Knock Curve—Method Used to Obtain Curve for Any Fuel.**

curve and the maximum-power-spark-advance curve for the particular engine in which the tests were conducted. For a fuel not to knock in this car, the car must be able to tolerate at least as much spark advance at all speeds as that produced by the distributor-advance mechanism. Wherever the solid line representing the borderline curve for the test fuel falls below the distributor-spark-advance curve, the engine is considered to be knocking. The borderline curve for this fuel indicates that it will knock at relatively low speeds in the range from 700 rpm to 1,800 rpm.

In this example, the actual knock-die-out points obtained on the road are indicated by the heavy dots to illustrate the number of points actually obtained in the development of a curve of this type. Each die-out point is checked twice on the road; and if there is still some doubt in the operator's mind, additional accelerations are made until the knock-die-out speed for any spark advance has been established definitely. The individual points are not shown on the border-

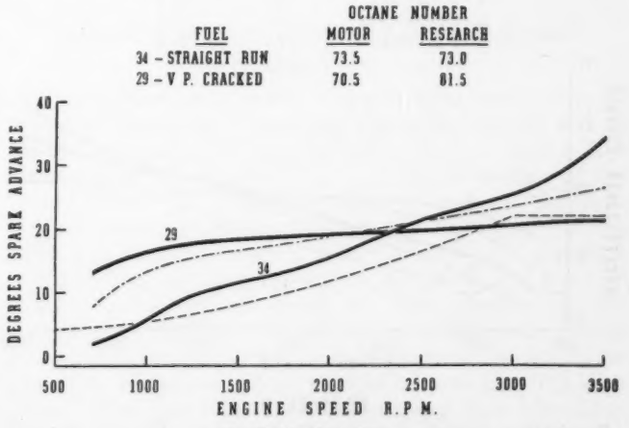


**FIGURE 2**

**Borderline Knock Curves — *Comparison:* Straight-run Gasoline and Vapor-Phase Cracked Gasoline.**

line curves given in this paper, but they all were obtained and recorded in a similar manner.

The borderline curve obtained in this way will be indicative only of the anti-knock characteristics of the test fuel in the particular type of engine in which the tests were conducted, inasmuch as there is a dif-

ference in knocking tendencies between different types of engines. In general, the valve-in-head engine is inclined to knock more at low speed than the L-head engine, whereas the L-head engine generally knocks more severely at higher speeds. Because of this variation in engines, it is advisable to determine the borderline curve of a test fuel in at least one, and preferably duplicate, engines of each type. This procedure will give a remarkably good idea of the average road performance of a fuel in an average commercial car, even though the tests have been conducted in only two or four vehicles.

## PART 1

Automotive engineers and petroleum technologists have known for many years that often there is a marked difference in the road anti-knock performance of different types of gasoline. Perhaps the most outstanding example is the difference in road performance between a vapor-phase cracked gasoline and a straight-run gasoline of the same motor-method octane number. When these gasolines are tested by the standard CFR road-test procedure developed at Uniontown in 1932,[4] the vapor-phase cracked gasoline knocks most severely at high speed, and generally has a higher road octane value than the straight-run gasoline which knocks most severely at low speeds. Because the standard CFR road-test procedure rates a fuel solely on the basis of maximum knock intensity in the speed range wherein this knock occurs, and gives no indication of the road performance of a fuel at speeds at which no knock occurs, most investigators now feel this procedure tells only part of the story. When these same gasolines are rated by the borderline procedure, however (Figure 2), the remarkable difference in their road behavior is shown clearly. By the latter method it can be seen that the vapor-phase cracked gasoline (fuel 29) has extremely good low-speed anti-knock qualities, and that the straight-run gasoline (fuel 34) has extremely good high-speed anti-knock qualities.

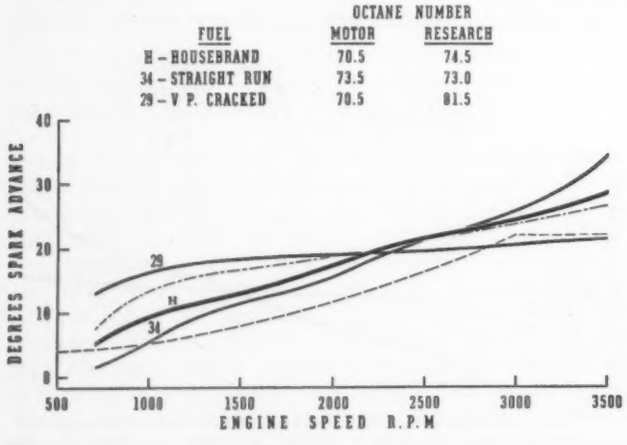


**FIGURE 3**

**Borderline Knock Curves—*Comparison:* Typical House-brand Gasoline, Straight-run Gasoline, and Vapor-Phase Cracked Gasoline.**

Obviously, if we could combine the good qualities of both these gasolines, we would have a highly satisfactory fuel. Inasmuch as vapor-phase cracked gasoline and straight-run gasoline represent two extremes in road behavior, they have been used throughout this work more or less as reference fuels, principally to indicate engine sensitivity to changes in the chemical composition of fuels.

Once having established the fact that the borderline method would differentiate between fuels of varying chemical composition, it was necessary next to determine the road anti-knock characteristics of

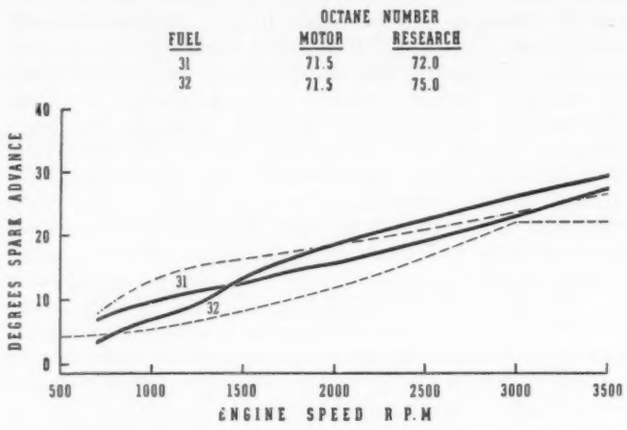


**FIGURE 4**

**Borderline Knock Curves—*Comparison:* High-Octane Material Concentrated in Light Fractions 31; and High-Octane Material Concentrated in Heavy Fractions 32.**

average commercial gasolines by this method. The results on some 15 different brands indicated that the average fuel has a tendency to knock at low speeds, although its high-speed performance is generally adequate. This is shown in Figure 3, which gives the borderline curve of a typical house-brand gasoline "H" in comparison to the borderline curves of the vapor-phase cracked gasoline and the straight-run gasoline. It will be noted that a 2° or 3° advance in distributor spark timing would cause fuel "H" to knock at low speeds. When referred to the maximum-power-spark-timing curve, this fuel is definitely unsatisfactory at all speeds below 2,400 rpm. An improvement in the low-speed anti-knock characteristics of commercial fuels, therefore, is desirable.

### Methods for Improving Low-Speed Anti-Knock Performance

In a paper by Bartholomew, Chalk, and Brewster,[5] it was pointed out that faulty fuel distribution in the manifold often caused road anti-knock depreciation of fuels having high-octane material concentrated in the heavy end, in comparison to fuels of equal temperature sensitivity having high-octane material concentrated in the light end. This work suggested that perhaps improved low-speed performance could be obtained by concentrating high-octane material in the light fractions. Figure 4 shows the difference in the borderline curves of a fuel of each type. It will be noted that fuel 31, having the high-octane material concentrated in the light fractions, is superior at low speeds to fuel 32, in spite of the fact that the research octane number of fuel 32 is 3.0 octane numbers higher than that of fuel 31. In one of the cars used, fuel 32 was superior at all speeds to fuel 31—indicating that this car had a remarkably good induction system. Thus, the low-speed superiority of fuel 31 over fuel 32 may not be an inherent fuel quality, but possibly may be due to an engine manifold weakness which, if corrected by the car manufacturer, would remove the advantage of concentrat-

ing high-octane material in the volatile fractions of the fuel.

However, as this idea of concentrating high-octane material in the light fractions of the fuel to improve low-speed anti-knock performance seemed to have merit, it was decided to make up a fuel which would

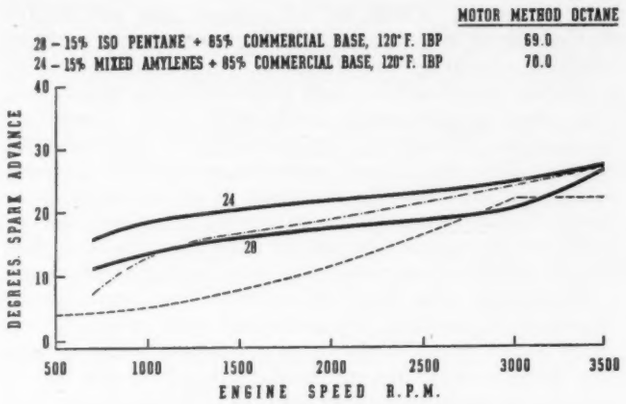
MOTOR METHOD OCTANE
28 – 15% ISO PENTANE + 85% COMMERCIAL BASE, 120° F. IBP 69.0
24 – 15% MIXED AMYLENES + 85% COMMERCIAL BASE, 120° F. IBP 70.0
DEGREES SPARK ADVANCE
ENGINE SPEED R.P.M.
24
28

**FIGURE 5**

**Borderline Knock Curves—Relative Effect of High-Octane Light Saturated and Unsaturated Blending Stocks.**

have the highest possible octane value in the light fractions. Mixed amylenes finally were selected as the blending agent, because they have a blending octane value of approximately 125. The borderline tests of this fuel showed a low-speed anti-knock improvement which was remarkable in contrast to any of the former experiments. A review of previous work revealed that the distinguishing fact was that, in the former blends, the high-octane material had all been paraffinic rather than olefinic in nature. Thus, the conception of the influence of chemical composition on low-speed anti-knock performance was formed.

The borderline curves in Figure 5 clearly illustrate the difference between paraffinic and olefinic material

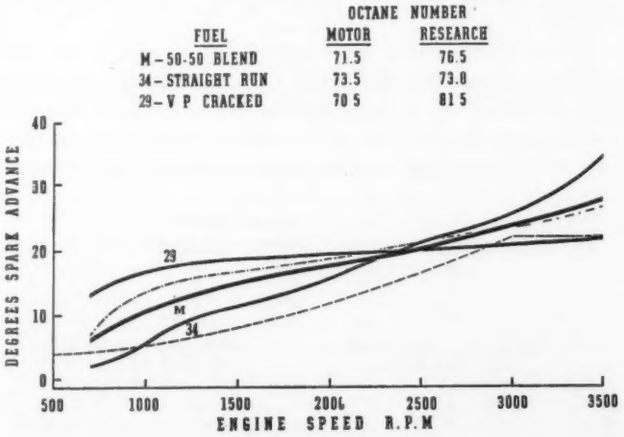


**FIGURE 6**

**Borderline Knock Curves—*Comparison:* 50-50 Blend of Straight-run and Vapor-Phase Cracked Gasolines, Straight-run Gasoline, and Vapor-Phase Cracked Gasoline.**

in the light fractions. Fuel 28 is a commercial base stock in which the fractions from the initial boiling point to 120° F. have been replaced with *iso*pentane. Fuel 24 is the same topped base stock containing mixed amylenes in the front end. The *iso*pentane used had a motor-method octane number of approximately 91, and the mixed amylenes an octane number of approximately 88—which gave fuel 28 a slight advantage over fuel 24 on the basis of the motor-method octane number of the volatile fractions. It is obvious, however, that the road anti-knock performance of fuel 24 is definitely superior to that of fuel 28, indicating that the chemical composition of the light fractions may be an important consideration. This superiority of light olefinic material over light paraffinic material is supported further by the fact that, when these two fuels were tested in the car with the particularly good induction system, fuel 24 was still superior to fuel 28. It seems, therefore, that the low-speed performance of the average gasoline may be improved by concentrating high-octane olefinic material in the volatile fractions. It should be pointed out, however, that this conclusion is based on a comparison of fuels of equal motor-method value but varying research-method value. It is possible that, had the comparison been made between fuels of equal

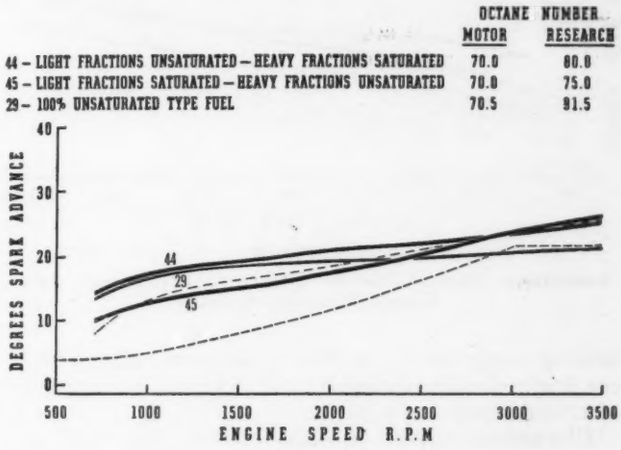


**FIGURE 7**

**Borderline Knock Curves—Effect of Selective Blending.**

research octane number, the differences between the light olefinic and the light paraffinic blending material might not have been so great.

### Effect of Selective Blending on Low-Speed Anti-Knock Performance

This preliminary work showed that some sort of selective blending of straight-run and cracked stocks should be employed to produce a motor fuel which more nearly would conform with the definition of the "ideal" fuel. Obviously, a 50:50 blend of the full-boiling-range stocks was not the answer; for, as shown in Figure 6, such a blend produces a rather average fuel, not as good at low speeds as the cracked gasoline and not as good at high speeds as the straight-run gasoline. Tests showing the superiority of light olefinic material in the front end of a fuel as a booster of low-speed anti-knock characteristics suggested that, perhaps by fractionating and blending, it might be possible to produce a gasoline having the good qualities of both straight-run and vapor-phase cracked fuels. The results of this experiment are shown in Figure 7. A highly cracked fuel was cut into two equal portions by distillation. To the light fraction a heavy paraffinic stock was added to produce fuel 44. In contrast to this, a light saturated fraction was added to the heavy cracked material, producing fuel 45. The borderline curve of the 100 percent cracked fuel (fuel 29) is shown for compari-

son. By selectively blending the light cracked fractions with the heavy straight-run material, the good low-speed characteristics of the highly cracked fuel were retained, and at the same time there was a noticeable improvement in its high-speed performance. Fuel 44 does not have as good high-speed performance as a straight-run fuel alone; but, from the standpoint of engine requirements with respect to speed, this fuel is apparently quite satisfactory. These results gave the first definite indication that it might be possible to improve motor fuels considerably by blending narrow cuts rather than full-

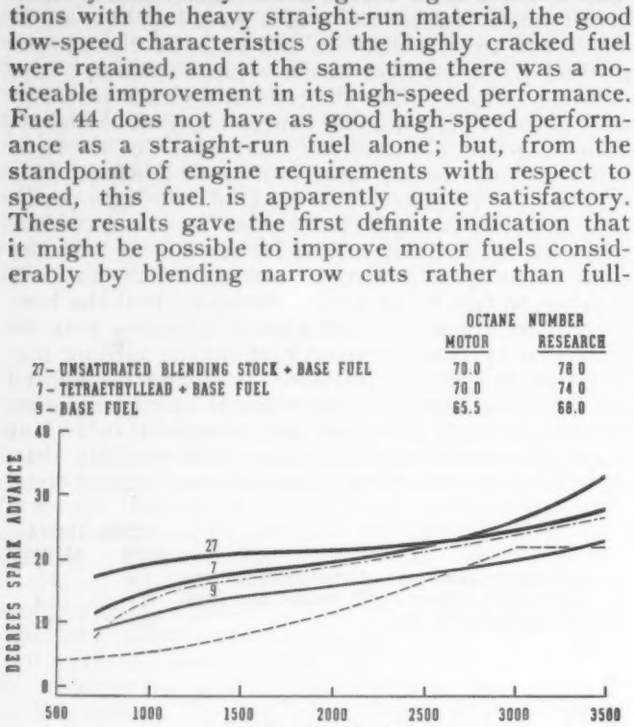
OCTANE NUMBER
MOTOR
RESEARCH
27 - UNSATURATED BLENDING STOCK + BASE FUEL 70.0 78.0
7 - TETRAETHYLLEAD + BASE FUEL 70.0 74.0
9 - BASE FUEL 65.5 68.0
DEGREES SPARK ADVANCE
ENGINE SPEED R P M

**FIGURE 8**
**Borderline Knock Curves—Effect of Different Anti-Knock Blending Agents.**

boiling-range stocks, or that some new refinery process might be devised which would yield a motor fuel of this desired composition.

The refiner should consider not only the road anti-knock qualities of the base gasoline, but its response to additions of tetraethyl lead, for the reason that most refiners use lead to obtain and maintain the proper anti-knock level of their commercial products. Having established the octane level of a given product, it is essential that this leaded fuel, rather than the base fuel itself, should conform to the definition of the "ideal" fuel. By referring to the borderline curves shown in Figure 8, it is apparent that the addition of lead to the average base stock (fuel 7) has a tendency to increase the high-speed anti-knock performance to a greater extent than the low-speed performance. Apparently from this work, if the "ideal" fuel is to contain lead, the base stock should have low-speed anti-knock qualities such that when lead is added the borderline curve of the "ideal" fuel will take the proper shape in relation to the spark-advance requirements of the engine. Previous experiments have indicated that the addition of light unsaturated material, as shown in fuel 27, will improve greatly the low-speed characteristics of a fuel. This suggests that perhaps the "ideal" fuel should be made by adding both unsaturated material and tetraethyl lead to the base stock, and indicates the necessity of more extensive work on the lead susceptibility of any base fuels which possibly might be considered.

## PART 2

A review of these preliminary tests covering the possibility of producing improved motor fuels by blending selected stocks indicates that a fuel in which the volatile fractions are comprised largely of high-octane olefinic material, and the heavy fractions are comprised largely of saturated hydrocarbons, most nearly approaches the definition of an "ideal" fuel. The commercial production of such a fuel, however, would necessitate considerable changes in refining equipment, or perhaps the development of entirely new processes. There is, of course, the possibility that some of the newer existing processes, such as catalytic cracking and catalytic reforming, alone or in proper combination, may produce fuels which will meet these requirements with little or no alteration. Changes in refining equipment might entail the addition of a few specialized units to supplement present equipment or the construction of an entirely new plant. Before extensive equipment changes can be justified, the refiner should be sure that the new fuel will be relatively satisfactory for a number of years.

Obviously, this kind of information best can be obtained by testing the proposed fuel types in engines which seem likely to be produced in the future. The design of future motor cars is, of course, up to the engine manufacturers; but, by extrapolating past trends, it appears that future engines probably will have higher compression ratios and, thus, require fuels of higher anti-knock value. In accordance with these ideas, the 17 gasolines in the "N" series of fuels shown in Table 2 were prepared, derived from various sources and methods of manufacture. These fuels were cut into two fractions, the light fraction representing the material boiling between the initial boiling point and 235° F., the heavy fraction representing the material boiling between 235° F. and the end point. Both fractions of each fuel were analyzed separately, and their content of the four broad types of hydrocarbons—paraffins, olefins, naphthenes, and aromatics—determined. The method of analysis used was essentially that of Kurtz and Headington, [6] with some minor modifications as described in Appendix "A." These hydrocarbon analyses, together with the full descriptions of the blends and the laboratory inspection data on each fuel, are given in Tables 1 and 2.

All of these fuels were rated clear, and with the addition of several different concentrations of tetraethyl lead, in an L-head and a valve-in-head engine. These engines had the following compression ratios and corresponding road octane number requirement

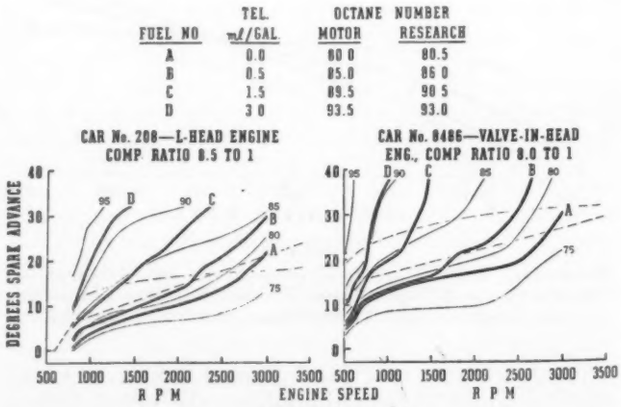


**FIGURE 9**
**Borderline Knock Curves—N-12: 47 percent California Straight-run, 310°-F-End Point; 41 Percent Heavy Alkylate; 7 Percent *n*Butane; 5 Percent Reference Fuel F-3.**

to just satisfy the maximum-power-spark-timing curve, as indicated by reference-fuel blends:

| L-HEAD ENGINE, CAR 208 | | | VALVE-IN-HEAD ENGINE, CAR 8486 | | |
|---|---|---|---|---|---|
| Compression Ratio | Octane No. Requirement | | Compression Ratio | Octane No. Requirement | |
| | Motor | Research | | Motor | Research |
| 8.5..... | 91.0 | 94.6 | 8.0..... | 88.5 | 90.1 |

These cars were selected because previous tests had indicated that, if a fuel would satisfy the high-speed anti-knock requirements of an L-head engine and the low-speed anti-knock requirements of a valve-in-head engine, the liklihood of its being satisfactory in all engines was extremely good. The borderline curves of the fuels shown in Figures 9 through 12 illustrate the highlights of this investigation. For comparison, the results in the L-head engine and the valve-in-head engine are given side by side.

### Variation in Road Lead Susceptibility of Different Fuels

Figure 9 gives the borderline curves of fuel N-12, a saturated-type gasoline—clear, and with the addition of three different concentrations of tetraethyl

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 82.0 | 94.5 |
| B | 0.5 | 82.5 | 96.5 |
| C | 1.5 | 84.0 | 98.0 |
| D | 3.0 | 85.0 | 99.0 |

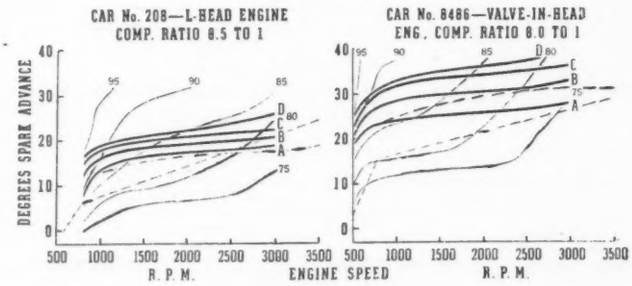


**FIGURE 10**

**Borderline Knock Curves—N-18: 100 Percent Polymer Gasoline.**

lead. This fuel obviously is similar in performance to its lower-octane counterpart, the straight-run gasoline shown in previous curves. Its high-speed performance is much better than its low-speed performance, and the addition of lead to this fuel improves the high-speed performance out of proportion to the improvement obtained at low speeds. Similar results for fuel N-18, a highly saturated-type gasoline produced by polymerization, shown in Figure 10, indicate that this fuel has remarkable good low-speed characteristics but relatively poor high-speed anti-knock properties. Although tetraethyl-lead addition is not particularly effective in increasing the anti-knock performance of this fuel, lead addition does help it at high speeds, at which speeds the fuel is inherently weak. For this reason, the poor motor-method lead susceptibility of this fuel may be misleading at times.

Fuel N-19, which is a 50:50 blend of the saturated- and unsaturated-type fuels N-12 and N-18, is superior to either of its two components both in road anti-knock performance and in road lead susceptibility throughout the speed range, as shown in Figure 11.

Fuel N-13 (Figure 12) illustrates the possibilities of selective blending, i.e., concentrating the unsaturated hydrocarbons in the volatile fractions and the saturated-type hydrocarbons in the heavy fractions. Compared to the other fuels, N-13 has better overall road anti-knock performance and at the same time

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 82.0 | 92.0 |
| B | 0.5 | 84.5 | 95.0 |
| C | 1.5 | 87.0 | 98.0 |
| D | 3.0 | 89.0 | 99.0 |

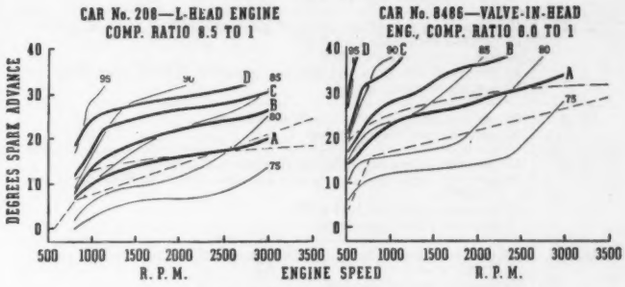


**FIGURE 11**

**Borderline Knock Curves—N-19: 48 Percent Polymer Gasoline; 52 Percent Saturated-Type Fuel (Fuel N-12).**

better road lead susceptibility at all speeds. It will be noted that, especially in the L-head engine, the addition of lead to this type of blend improves the low-speed characteristics to almost the same degree as it improves the high-speed anti-knock properties. Unfortunately, the data obtained in the valve-in-head engine for this fuel were not obtained on the same day nor under the same conditions as the data shown for fuels N-18 and N-19. For this reason, borderline curves for fuel N-13 are not directly comparable to the others. The reference-fuel pattern indicates that the car rated all fuels at higher spark advances—which past experience has shown tends to minimize the apparent effect of tetraethyl-lead additions.

These results confirmed the indications of prelim-

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 80.0 | 91.0 |
| B | 0.5 | 83.0 | 94.5 |
| C | 1.5 | 85.5 | 97.0 |
| D | 3.0 | 88.0 | 98.5 |

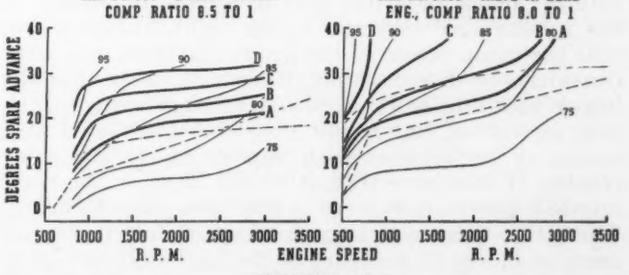


**FIGURE 12**

**Borderline Knock Curves—N-13: 50 Percent Vapor-Phase Cracked, Initial Boiling Point to 240° F; 20 Percent Heavy Alkylate; 15 Percent Naphthenic Heavy Straight-run; 15 Percent Reference Fuel F-3.**

inary experiments that an improved motor fuel can be prepared by blending selected cuts rather than full-boiling-range stocks. They proved further that this is a valid possibility for producing fuels of the future, because the effect of this type of blending apparently is independent of the octane value of the

**TABLE 1**

**Description of Test Fuels**

| "N" SERIES OF FUELS | | "E" SERIES OF FUELS | |
|---|---|---|---|
| **Fuel No.** | **Description** | **Fuel No.** | **Description** |
| N-12 | 47 percent California straight-run gasoline, 310° F. end point<br>41 percent heavy alkylate<br>7 percent normal butane<br>5 percent reference fuel F-3* | E-1 | 50 percent vapor-phase cracked gasoline, initial boiling point to 275° F.<br>50 percent heavy alkylate |
| N-13 | 50 percent vapor-phase cracked gasoline, initial boiling point to 240° F.<br>20 percent heavy alkylate<br>15 percent heavy naphthenic straight-run gasoline<br>15 percent reference fuel F-3* | E-2 | 50 percent vapor-phase cracked gasoline, initial boiling point to 275° F.<br>50 percent heavy catalytically reformed gasoline |
| N-14 | 40 percent vapor-phase cracked gasoline, 240° F. to end point<br>19 percent reference fuel F-3*<br>19 percent *iso*propyl ether<br>12 percent California straight-run gasoline, 200° F. to end point<br>10 percent normal butane | E-3 | 50 percent vapor-phase cracked gasoline, initial boiling point to 275° F.<br>50 percent heavy naphthenic straight-run gasoline |
| N-15 | 50 percent catalytically cracked gasoline<br>50 percent polymer gasoline | E-4 | 100 percent polymer gasoline |
| N-16 | 45 percent heavy naphthenic straight-run gasoline<br>38 percent vapor-phase cracked gasoline, initial boiling point to 240° F.<br>10 percent reference fuel F-3*<br>7 percent mixed amylenes | E-5 | 25 percent CHP† cracked gasoline from Illinois crude oil, initial boiling point to 275° F.<br>25 percent catalytically dehydrogenated light straight-run gasoline from Illinois crude oil<br>50 percent catalytically reformed heavy gasoline |
| N-17 | 50 percent vapor-phase cracked gasoline, initial boiling point to 240° F.<br>50 percent heavy alkylate | E-6 | 70 percent CHP† cracked gasoline from Illinois crude oil<br>30 percent straight-run gasoline, 325° F. end point |
| N-18 | 100 percent polymer gasoline | E-7 | 85 percent fuel E-6<br>15 percent fuel E-4 |
| N-19 | 48 percent polymer gasoline<br>48 percent fuel N-12<br>4 percent normal butane | E-8 | 85 percent fuel E-6<br>7.5 percent fuel E-4, initial boiling point to 300° F., cut<br>7.5 percent catalytically reformed heavy gasoline |
| N-20 | Blend of Mid-Continent straight-run and cracked gasolines | E-15 | 100 percent catalytically cracked gasoline |
| N-22 | 100 percent catalytically cracked gasoline | E-16 | Catalytically cracked gasoline in which last 10 percent of boiling range has been replaced with heavy alkylate |
| N-23 | 50 percent polymer gasoline<br>50 percent fuel N-20 | E-17 | 100 percent vapor-phase cracked gasoline |
| N-24 | 25 percent vapor-phase cracked gasoline, initial boiling point to 240° F.<br>75 percent catalytically reformed gasoline. | E-18 | 100 percent Texas straight-run gasoline |
| N-25 | 25 percent vapor-phase cracked gasoline, initial boiling point to 240° F.<br>75 percent fuel N-20 | | |
| N-26 | 55 percent reference fuel C-12<br>25 percent reference fuel A-6<br>20 percent absolute alcohol | | |
| N-27 | 100 percent catalytically cracked gasoline | | |
| N-28 | 100 percent catalytically reformed gasoline | | |
| N-29 | Catalytically cracked gasoline in which last 10 percent of boiling range has been replaced with heavy alkylate | | |

* Reference fuel F-3 is technical *iso*octane.
† Combination high-pressure.

fuels or the compression ration of the engines. These results further indicated that it is most important to use unsaturated material in the light fractions, but that the composition of the heavy fractions may vary considerably. For example, it seemed likely that the heavy blending stock need not be necessarily paraffinic in nature, but might consist of alkylated aromatics of naphthenes with approximately the same results. If this were true, it would increase the commercial practicability of such selective blending. Then, too, there was some indication that, if a small amount (10 to 15 percent) of the high-boiling olefins in a highly unsaturated-type fuel were replaced with high-boiling paraffinic material, a much improved product would be obtained.

In order to evaluate these indications in a more quantitative manner, the 11 fuels of the "E" series were prepared. This time each fuel was cut into three fractions, rather than two, for hydrocarbon analysis, because it was thought that the analyses of the three cuts would give more useful information regarding the effect of hydrocarbon type on road anti-knock performance. The light fraction comprised the material boiling up to 140° F.; the middle fraction, the material boiling between 140° and 235° F; and the heavy fraction, the material boiling from 235° F to the end point. The hydrocarbon types in each fraction were determined as described for the "N" series of fuels. These hydrocarbon analyses, together with the full descriptions of the blends and the laboratory inspection data on each fuel, are given in Tables 1 and 3.

All of these fuels were tested clear, and with the addition of 0.5 ml, 1.5 ml, and 3.0 ml of tetraethyl lead per gallon. It will be noted that no attempt was made to blend these fuels to any predetermined octane level, with the result that the fuels varied in anti-knock value from 66.5 to 87.0 octane number (motor method). Obviously, satisfactory road ratings over this entire octane range could not be obtained using engines of only one compression ratio; and, as little data are available in the literature covering the effect of compression-ratio changes on fuel ratings, it was decided to rate all of these fuels, insofar as possible, in both an L-head and a valve-in-head engine at several compression ratios. The compression ratios used, together with the corresponding road octane values which will just satisfy the maxi-

**Table 2**

**"N" Series of Fuels**

| Fuel No. | N-12 | N-13 | N-14 | N-15 | N-16 | N-17 | N-18 | N-19 | N-20 | N-22 | N-23 | N-24 | N-25 | N-26 | N-27 | N-28 | N-29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gravity, deg. API** | **63.4** | **63.6** | **61.0** | **60.7** | **56.8** | **63.5** | **65.8** | **64.9** | **65.3** | **55.3** | **65.6** | **58.9** | **67.1** | **59.9** | **59.0** | **55.8** | **58.0** |
| **ASTM Distillation, in °F.:** | | | | | | | | | | | | | | | | | |
| Initial boiling point | 96 | 100 | 99 | 98 | 102 | 106 | 96 | 100 | 101 | 95 | 102 | 89 | 101 | 130 | 104 | 98 | 103 |
| 10-percent point | 146 | 136 | 141 | 140 | 136 | 130 | 142 | 144 | 138 | 136 | 141 | 126 | 132 | 145 | 137 | 147 | 149 |
| 20-percent point | 191 | 158 | 168 | 174 | 157 | 154 | 178 | 182 | 160 | 172 | 167 | 149 | 148 | 152 | 159 | 177 | 178 |
| 30-percent point | 223 | 181 | 186 | 203 | 182 | 186 | 200 | 208 | 178 | 207 | 190 | 176 | 164 | 156 | 184 | 206 | 205 |
| 40-percent point | 249 | 200 | 200 | 228 | 211 | 227 | 217 | 229 | 197 | 243 | 206 | 198 | 182 | 159 | 200 | 227 | 226 |
| 50-percent point | 280 | 221 | 220 | 246 | 239 | 301 | 232 | 248 | 214 | 270 | 221 | 218 | 198 | 162 | 228 | 243 | 246 |
| 60-percent point | 314 | 245 | 250 | 269 | 270 | 342 | 252 | 257 | 231 | 297 | 236 | 238 | 213 | 195 | 263 | 263 | 268 |
| 70-percent point | 340 | 290 | 293 | 297 | 303 | 350 | 275 | 308 | 242 | 322 | 255 | 261 | 229 | 230 | 290 | 288 | 294 |
| 80-percent point | 355 | 342 | 337 | 326 | 327 | 357 | 298 | 337 | 260 | 352 | 276 | 298 | 250 | 254 | 326 | 325 | 320 |
| 90-percent point | 365 | 356 | 386 | 369 | 351 | 364 | 336 | 362 | 287 | 382 | 310 | 350 | 281 | 302 | 360 | 363 | 344 |
| End point | 386 | 395 | 422 | 410 | 402 | 399 | 404 | 396 | 335 | 408 | 386 | 390 | 331 | ... | 414 | 394 | 369 |
| Recovery, percent | 95.8 | 97.3 | 95.6 | 96.9 | 98.0 | 98.0 | 97.0 | 96.1 | 97.2 | 96.8 | 97.0 | 95.5 | 97.0 | 98.0 | 97.0 | 94.0 | 96.9 |
| Residue, percent | 1.2 | 0.9 | 1.1 | 1.0 | 0.5 | 1.2 | 0.9 | 1.2 | 1.0 | 0.8 | 1.1 | 1.2 | 1.2 | 1.2 | 1.4 | 0.9 | 1.0 |
| Loss, percent | 3.0 | 1.8 | 3.3 | 2.1 | 1.5 | 0.8 | 2.1 | 2.7 | 1.8 | 1.9 | 1.9 | 3.3 | 1.8 | 0.8 | 1.6 | 5.1 | 2.1 |
| **Hydrocarbon Analysis:** | | | | | | | | | | | | | | | | | |
| Light half, initial boiling point to 235° F.: | | | | | | | | | | | | | | | | | |
| Percent of total fuel | 43.8 | 65.2 | 62.2 | 54.0 | 57.0 | 49.2 | 55.4 | 51.3 | 69.6 | 45.8 | 62.0 | 67.6 | 80.0 | .... | 55.6 | 54.9 | 55.1 |
| Percent olefins | 4 | 55 | 52 | 66 | 59 | 73 | 80 | 57 | 8 | 42 | 44 | 30 | 31 | .... | 60 | 20 | 53 |
| Percent aromatics | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 1 | 4 | 3 | 5 | 1 | .... | 2 | 11 | 4 |
| Percent paraffins | 69 | 43 | 48 | 25 | 35 | 23 | 18 | 41 | 69 | 54 | 47 | 54 | 44 | .... | 24 | 54 | 32 |
| Percent naphthenes | 27 | 2 | 0 | 7 | 6 | 4 | 0 | 2 | 22 | 0 | 6 | 11 | 24 | .... | 14 | 15 | 11 |
| Heavy half, 235° F. to the end point: | | | | | | | | | | | | | | | | | |
| Percent total fuel | 56.2 | 34.8 | 37.8 | 46.0 | 43.0 | 50.8 | 44.6 | 48.7 | 30.4 | 54.2 | 38.0 | 32.4 | 20.0 | .... | 44.4 | 45.1 | 44.9 |
| Percent olefins | 3 | 10 | 46 | 54 | 13 | 7 | 85 | 40 | 15 | 11 | 42 | 13 | 27 | .... | 32 | 7 | 24 |
| Percent aromatics | 4 | 5 | 17 | 16 | 8 | 0 | 3 | 0 | 8 | 37 | 11 | 54 | 4 | .... | 26 | 55 | 31 |
| Percent paraffins | 75 | 54 | 24 | 17 | 0 | 90 | 12 | 55 | 36 | 19 | 36 | 24 | 29 | .... | 27 | 29 | 21 |
| Percent naphthenes | 18 | 31 | 13 | 13 | 79 | 3 | 0 | 5 | 41 | 33 | 11 | 9 | 40 | .... | 15 | 9 | 24 |
| Total fuel: | | | | | | | | | | | | | | | | | |
| Percent olefins | 3 | 39 | 49 | 60 | 39 | 40 | 82 | 49 | 10 | 25 | 43 | 24 | 30 | .... | 48 | 14 | 40 |
| Percent aromatics | 2 | 2 | 7 | 9 | 4 | 0 | 2 | 0 | 4 | 22 | 6 | 21 | 2 | .... | 13 | 31 | 16 |
| Percent paraffins | 73 | 47 | 39 | 21 | 20 | 57 | 16 | 47 | 59 | 35 | 43 | 45 | 41 | .... | 25 | 43 | 27 |
| Percent naphthenes | 22 | 12 | 5 | 10 | 37 | 3 | 0 | 4 | 27 | 18 | 8 | 10 | 27 | .... | 14 | 12 | 17 |
| **Octane No., ASTM Motor Method:** | | | | | | | | | | | | | | | | | |
| Clear | 80.0 | 80.0 | 80.0 | 80.5 | 78.0 | 81.5 | 82.0 | 82.0 | .... | 76.5 | .... | 76.0 | .... | 80.5 | 78.0 | 76.5 | 80.0 |
| Plus 0.5 ml TEL* per gal. | 85.0 | 83.0 | 82.5 | 82.0 | 80.5 | 83.5 | 82.5 | 84.5 | .... | 79.5 | .... | 80.0 | .... | .... | 80.0 | 80.5 | 82.0 |
| Plus 1.5 ml TEL per gal. | 89.5 | 85.5 | 86.0 | 84.0 | 82.0 | 86.5 | 84.0 | 87.0 | .... | 82.5 | 83.5 | 82.5 | .... | .... | 82.0 | 83.0 | 84.0 |
| Plus 3.0 ml TEL per gal. | 93.5 | 88.0 | 89.0 | 85.5 | 84.5 | 88.0 | 85.0 | 89.0 | 82.5 | 84.5 | .... | 85.0 | 83.0 | .... | 83.5 | 86.5 | 85.0 |
| **Octane No., CFR Research Method:** | | | | | | | | | | | | | | | | | |
| Clear | 80.5 | 91.0 | 85.5 | 92.0 | 88.0 | 91.0 | 94.5 | 92.0 | .... | 87.0 | .... | 87.0 | .... | .... | 90.0 | 85.0 | 93.0 |
| Plus 0.5 ml TEL per gal. | 86.0 | 94.5 | 89.0 | 95.0 | 93.0 | 95.0 | 96.5 | 95.0 | .... | 90.0 | .... | 90.5 | .... | .... | 93.0 | 89.0 | 95.0 |
| Plus 1.5 ml TEL per gal. | 90.5 | 97.0 | 93.0 | 97.0 | 95.0 | 97.5 | 98.0 | 98.0 | .... | 92.5 | 93.5 | 93.5 | .... | .... | 95.0 | 92.5 | 97.5 |
| Plus 3.0 ml TEL per gal. | 93.0 | 98.5 | 95.5 | 98.5 | 97.5 | 99.5 | 99.0 | 99.0 | 83.0 | 94.5 | .... | 95.5 | 88.5 | .... | 96.5 | 95.0 | 98.5 |

* Tetraethyl lead.

mum-power-spark-timing curve, as indicated by reference-fuel blends, are as follows:

| L-HEAD ENGINE, CAR 222 | | | VALVE-IN-HEAD ENGINE, CAR 215 | | |
|---|---|---|---|---|---|
| Compression Ratio | Octane No. Requirement | | Compression Ratio | Octane No. Requirement | |
| | Motor | Research | | Motor | Research |
| 6.9 | 74.0 | 76.5 | 6.5 | 83.0 | 86.3 |
| 7.5 | 78.0 | 80.7 | 8.0 | 88.0 | 91.7 |
| 8.5 | 83.5 | 86.9 | 9.0 | 93.0 | 96.4 |
| 9 4 | 88.0 | 91.7 | | | |

For illustrative purposes, only the results obtained using one ratio for each car have been included, and they have been selected so that the fuels under consideration would be rated within reasonable spark-advance limits. It might be pointed out briefly that, when the high-octane-number fuels were rated using the low compression-ratio heads, excessive spark advance was necessary to obtain any rating at all, and such ratings could be obtained then only at low speeds. If it was necessary to advance the spark much above maximum-power spark timing for the engine, there was a noticeable drop in power, and a drop in the knocking tendency of the fuel, which gave results not comparable with the results obtained under more reasonable operating conditions.

### Effect of Chemical Composition of High-Boiling Fractions on Lead Susceptibility

The results of this investigation are given in Figures 13 through 17. Fuels E-1, -2, and -3, shown in Figures 13, 14, and 15, illustrate the difference in road anti-knock performance between blends of the same light olefinic material with paraffinic, aromatic, and naphthenic heavy material, respectively. These results indicate that paraffinic material is preferable as a heavy blending agent, but that either aromatic material or naphthenic material would be a satisfactory substitute in the order named. The differences between these three types of high-boiling blending materials are more apparent if evaluated in terms of their relative effect on the road lead susceptibility of the blends. The fuel containing the heavy paraffinic material has the best road lead susceptibility in both the low- and high-speed range.

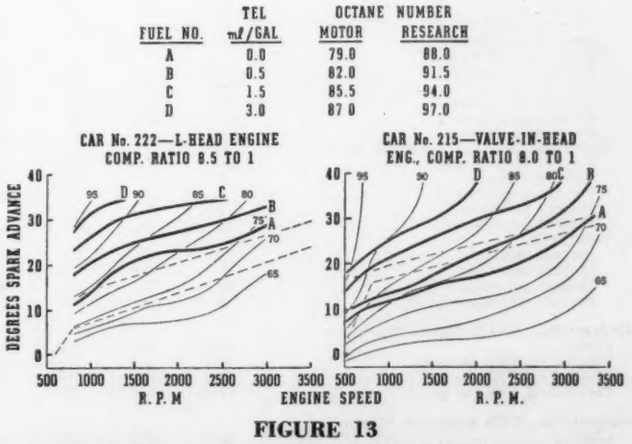
FUEL NO.
TEL ml/GAL
OCTANE NUMBER MOTOR
OCTANE NUMBER RESEARCH
A 0.0 79.0 88.0
B 0.5 82.0 91.5
C 1.5 85.5 94.0
D 3.0 87 0 97.0
CAR No. 222—L-HEAD ENGINE COMP. RATIO 8.5 TO 1
CAR No. 215—VALVE-IN-HEAD ENG., COMP. RATIO 8.0 TO 1
DEGREES SPARK ADVANCE
R. P. M
ENGINE SPEED
R. P. M.

**FIGURE 13**

**Borderline Knock Curves—Fuel E-1: 50 Percent Vapor-Phase Cracked Gasoline, Initial Boiling Point to 275° F; 50 Percent Heavy Alkylate.**

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 73.5 | 86.5 |
| B | 0.5 | 78.5 | 90.0 |
| C | 1.5 | 82.0 | 93.5 |
| D | 3.0 | 84.0 | 95.0 |

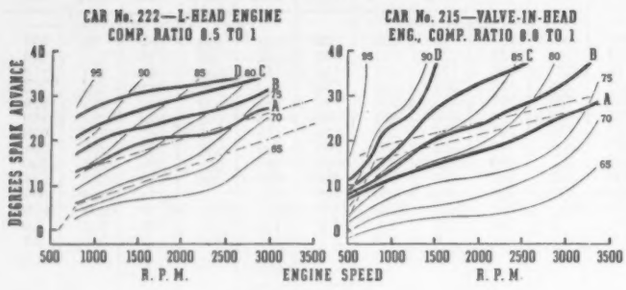


**FIGURE 14**

**Borderline Knock Curves—Fuel E-2: 50 Percent Vapor-Phase Cracked Gasoline, Initial Boiling Point to 275° F; 50 Percent Catalytically Reformed Gasoline, Approximate Boiling Range 200° to 400° F.**

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 72.5 | 82.5 |
| B | 0.5 | 78.0 | 88.0 |
| C | 1.5 | 81.0 | 91.0 |
| D | 3.0 | 83.0 | 93.0 |

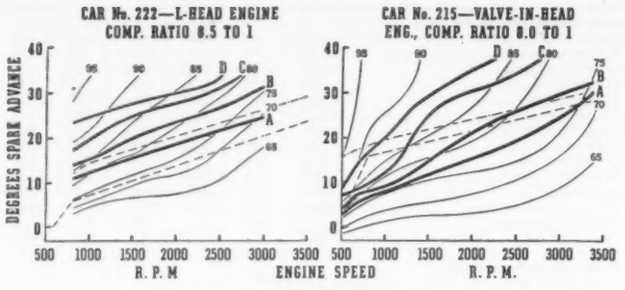


**FIGURE 15**

**Borderline Knock Curves—Fuel E-3: 50 Percent Vapor-Phase Cracked Gasoline, Initial Boiling Point to 275° F; 50 Percent Heavy Naphthenic Straight-run Gasoline.**

The fuel containing aromatic heavy ends has relatively good high-speed lead response but approximately the same response at low speeds as that of the fuel containing heavy naphthenic material. This, incidentally, again points out the fact that the chemical composition of the high-boiling fractions may have a noticeable effect on the low-speed lead susceptibility of a fuel. This effect is well demonstrated by the two fuels designed for this purpose: fuels E-15 and E-16, Figures 16 and 17, respectively. Fuel E-15 is a 100-percent catalytically cracked gasoline, and fuel E-16 is the same gasoline in which the last 10 percent of the boiling range has been replaced with heavy paraffinic material. In this case, the substitution of high-boiling paraffins for aromatics not only removed the inherent tendency of this fuel to

**TABLE 3**

**"E" Series of Fuels**

| Fuel No. | E-1 | E-2 | E-3 | E-4 | E-5 | E-6 | E-7 | E-8 | E-15 | E-16 | E-17 | E-18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gravity, deg. API** | **61.1** | **58.6** | **57.8** | **65.3** | **57.4** | **61.3** | **62.0** | **60.6** | **57.7** | **60.3** | **57.9** | **53.1** |
| **ASTM Distillation, in °F.:** | | | | | | | | | | | | |
| Initial boiling point | 104 | 92 | 96 | 107 | 108 | 103 | 100 | 102 | 112 | 111 | 97 | 136 |
| 10-percent point | 146 | 133 | 136 | 127 | 150 | 146 | 139 | 144 | 148 | 150 | 131 | 189 |
| 20-percent point | 180 | 161 | 167 | 134 | 176 | 170 | 161 | 168 | 170 | 173 | 158 | 203 |
| 30-percent point | 216 | 186 | 187 | 140 | 198 | 192 | 180 | 190 | 194 | 192 | 190 | 215 |
| 40-percent point | 261 | 208 | 210 | 150 | 215 | 213 | 201 | 210 | 217 | 215 | 223 | 226 |
| 50-percent point | 306 | 228 | 236 | 162 | 230 | 233 | 220 | 230 | 237 | 234 | 250 | 238 |
| 60-percent point | 336 | 246 | 261 | 178 | 245 | 254 | 242 | 250 | 270 | 252 | 280 | 252 |
| 70-percent point | 352 | 262 | 288 | 200 | 262 | 273 | 262 | 270 | 295 | 268 | 308 | 271 |
| 80-percent point | 360 | 286 | 316 | 228 | 283 | 297 | 292 | 294 | 321 | 291 | 336 | 304 |
| 90-percent point | 368 | 322 | 350 | 280 | 318 | 334 | 325 | 331 | 352 | 319 | 370 | 344 |
| End point | 396 | 397 | 380 | 372 | 397 | 394 | 392 | 394 | 394 | 356 | 412 | 404 |
| Recovery, percent | 97.0 | 96.5 | 97.0 | 98.5 | 97.5 | 97.8 | 97.5 | 98.0 | 97.8 | 97.9 | 97.0 | 98.0 |
| Residue, percent | 1.3 | 1.3 | 1.0 | 0.9 | 1.0 | 1.2 | 1.3 | 1.1 | 0.6 | 0.7 | 1.2 | 1.1 |
| Loss, percent | 1.7 | 2.2 | 2.0 | 0.6 | 1.5 | 1.0 | 1.2 | 0.9 | 1.6 | 1.4 | 1.8 | 0.9 |
| Reid vapor pressure, lb. | 7.4 | 10.5 | 9.6 | 9.1 | 7.3 | 7.4 | 8.2 | 8.1 | .... | .... | 9.6 | 4.0 |
| Sulfur, percent: | | | | | | | | | | | | |
| Total | 0.017 | 0.103 | 0.022 | 0.028 | 0.010 | 0.034 | 0.035 | 0.036 | .... | .... | .... | .... |
| Mercaptan | Sweet | 0.006 | 0.004 | 0.011 | 0.001 | 0.001 | 0.005 | 0.005 | .... | .... | .... | .... |
| **Hydrocarbon Analysis:** | | | | | | | | | | | | |
| Light cut, initial boiling point to 140° F.: | | | | | | | | | | | | |
| Percent of total fuel | 16.6 | 26.4 | 21.6 | 43.2 | 16.0 | 20.8 | 20.8 | 17.6 | 16.4 | 16.2 | 21.3 | .... |
| Percent olefins | 69 | 52 | 73 | 34 | 21 | 29 | 30 | 28 | 60 | 60 | 70 | .... |
| Percent aromatics | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Percent paraffins | 31 | 48 | 27 | 66 | 79 | 71 | 70 | 72 | 40 | 40 | 30 | .... |
| Percent naphthenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Middle cut, 140° to 235° F.: | | | | | | | | | | | | |
| Percent of total fuel | 24.6 | 37.2 | 33.2 | 40.0 | 40.7 | 36.8 | 39.6 | 40.0 | 35.5 | 37.8 | 28.0 | .... |
| Percent olefins | 65 | 45 | 59 | 35 | 3 | 39 | 31 | 34 | 59 | 59 | 64 | .... |
| Percent aromatics | 4 | 13 | 3 | 9 | 33 | 0 | 3 | 2 | 3 | 0 | 7 | .... |
| Percent paraffins | 27 | 25 | 20 | 28 | 14 | 41 | 39 | 46 | 30 | 31 | 23 | .... |
| Percent naphthenes | 4 | 17 | 18 | 28 | 50 | 20 | 27 | 18 | 8 | 10 | 6 | .... |
| Heavy cut, 235° F.: to the end point: | | | | | | | | | | | | |
| Percent of total fuel | 58.8 | 36.4 | 45.2 | 16.8 | 43.3 | 42.4 | 39.6 | 42.4 | 48.1 | 46.0 | 50.7 | 100.0 |
| Percent olefins | 9 | 11 | 23 | 17 | 9 | 27 | 31 | 24 | 27 | 30 | 43 | 0 |
| Percent aromatics | 0 | 48 | 8 | 41 | 42 | 14 | 11 | 19 | 33 | 23 | 25 | 3 |
| Percent paraffins | 79 | 35 | 0 | 4 | 35 | 33 | 29 | 30 | 23 | 35 | 17 | 20 |
| Percent naphthenes | 12 | 6 | 69 | 38 | 14 | 26 | 29 | 27 | 17 | 12 | 15 | 77 |
| Total fuel: | | | | | | | | | | | | |
| Percent olefins | 33 | 35 | 46 | 32 | 9 | 32 | 31 | 29 | 44 | 46 | 55 | .... |
| Percent aromatics | 1 | 22 | 5 | 10 | 32 | 6 | 5 | 9 | 18 | 11 | 15 | .... |
| Percent paraffins | 58 | 35 | 12 | 40 | 33 | 44 | 42 | 44 | 29 | 33 | 21 | .... |
| Percent naphthenes | 8 | 8 | 37 | 18 | 26 | 18 | 22 | 18 | 9 | 10 | 9 | .... |
| **Octane No., ASTM Motor Method:** | | | | | | | | | | | | |
| Clear | 79.0 | 73.5 | 72.5 | 77.5 | 71.0 | 66.5 | 69.0 | 68.5 | 77.0 | 80.0 | 67.0 | 72.0 |
| Plus 0.5 ml TEL per gal. | 82.0 | 78.5 | 78.0 | 80.0 | 77.0 | 70.0 | 72.0 | 72.0 | 79.5 | 82.5 | 70.5 | 78.5 |
| Plus 1.5 ml TEL per gal. | 85.5 | 82.0 | 81.0 | 82.5 | 82.0 | 74.5 | 76.0 | 76.0 | 83.0 | 84.5 | 74.0 | 82.5 |
| Plus 3.0 ml TEL per gal. | 87.0 | 84.0 | 83.0 | 84.0 | 84.0 | 78.5 | 80.0 | 80.0 | 84.5 | 85.5 | 76.5 | 87.5 |
| **Octane No., CFR Research Method:** | | | | | | | | | | | | |
| Clear | 88.0 | 86.5 | 82.5 | 89.0 | 81.0 | 70.5 | 76.5 | 76.0 | 90.0 | 91.0 | 77.5 | 77.5 |
| Plus 0.5 ml TEL per gal. | 91.5 | 90.0 | 88.0 | 92.5 | 86.0 | 75.0 | 80.0 | 80.0 | 92.5 | 95.0 | 82.0 | 81.0 |
| Plus 1.5 ml TEL per gal. | 94.0 | 93.5 | 91.0 | 94.0 | 90.0 | 80.0 | 84.0 | 83.0 | 94.5 | 96.5 | 86.5 | 85.5 |
| Plus 3.0 ml TEL per gal. | 97.0 | 95.0 | 93.0 | 95.0 | 93.0 | 85.0 | 87.0 | 86.5 | 96.0 | 97.5 | 89.0 | 89.0 |

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 77.0 | 90.0 |
| B | 0.5 | 79.5 | 92.5 |
| C | 1.5 | 83.0 | 94.5 |
| D | 3.0 | 84.5 | 96.0 |

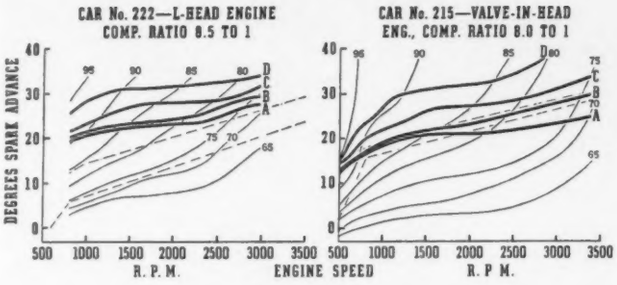


**FIGURE 16**

**Borderline Knock Curves—Fuel E-15: 100 Percent Catalytically Cracked Gasoline.**

knock at high speeds, but also improved the lead susceptibility throughout the entire speed range.

## PART 3

The tests on the "N" and "E" series of fuels again confirmed original indications that the gasoline which most nearly would approach the definition of an "ideal" fuel in road anti-knock performance would be one in which the light volatile portions were composed primarily of high-octane olefinic material and the heavy fractions were composed primarily of high-octane paraffinic material. It was shown, however, that improvements could be made in average fuels by altering their composition in any way which would tend to approach the composition of the "ideal" fuel:

1. By the substitution, in small amounts, of high-boiling paraffinic, aromatic, or naphthenic material for the high-boiling olefinic hydrocarbons normally contained in a highly-cracked fuel.
2. By the addition of light olefinic or aromatic material to a straight-run fuel.
3. By blending refinery stocks with due consideration to the effect of such blending on the road lead susceptibility throughout the speed range.
4. By using light olefinic material rather than light paraffinic material to obtain satisfactory volatility.

Commercial fuels cannot be made by cutting up present fuels, using the desirable portion and throwing the rest away. If these blending principles are to be applied to full-scale refinery operation, some means must be found of utilizing all of the fractions of all of the refinery stocks in the finished gasoline. The test results of the first attempt to make an improved motor fuel which would take refinery economics into consideration are shown by the borderline curves of the special blend, fuel E-5 (Figures 18 and 19), and are compared to similar curves for the present commercial production, fuel E-6. The composition of these two fuels is as follows:

| Fuel No. | Description |
|---|---|
| E-5 | 50 percent of a blend of high pressure-cracked gasoline and catalytically dehydrogenated light straight-run gasoline; approximate boiling range, initial boiling point to 275° F. |
| | 50 percent of catalytically reformed heavy cracked and heavy straight-run gasolines; approximate boiling range, 250° to 400° F. |
| E-6 | Regular commercial *CHP** unit production from Illinois charging stock, approximately: |
| | 30 percent of 325° F-end-point straight-run gasoline, and |
| | 70 percent of cracked and reformed gasolines. |

A comparison between the road anti-knock performance, and especially the road lead susceptibility, of these fuels indicates that a reasonable increase in the cost of production could well be tolerated to produce a fuel such as E-5. When we consider that this represents the first attempt to use this information in con-

* Combination high-pressure.

| FUEL NO. | TEL. ml/GAL. | OCTANE NUMBER MOTOR | RESEARCH |
|---|---|---|---|
| A | 0.0 | 80.0 | 91.0 |
| B | 0.5 | 82.5 | 95.0 |
| C | 1.5 | 84.5 | 96.5 |
| D | 3.0 | 85.5 | 97.5 |

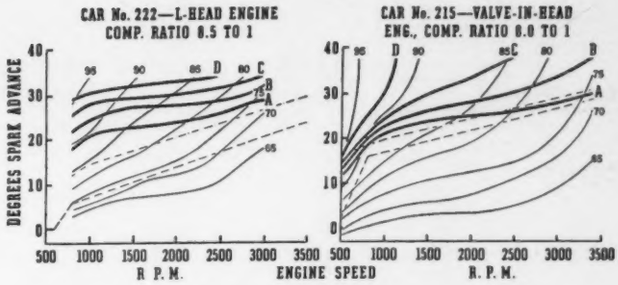


**FIGURE 17**

**Borderline Knock Curves—Fuel E-16: 90 Percent Catalytically Cracked Gasoline, Approximately 300° F. End Point; 10 Percent Heavy Alkylate, Approximate Boiling Range, 300° to 400° F.**

CAR NO 215, VALVE-IN-HEAD ENGINE, COMP. RATIO 8.0 to 1

| FUEL E-5—SPECIAL BLEND | | | | FUEL E-6—PRESENT BASE STOCK | | | |
|---|---|---|---|---|---|---|---|
| | TEL | OCTANE NUMBER | | | TEL | OCTANE NUMBER | |
| FUEL No | ml/GAL | MOTOR | RESEARCH | FUEL No | ml/GAL | MOTOR | RESEARCH |
| A | 0.0 | 71.0 | 81.0 | A | 0.0 | 66.5 | 70.5 |
| B | 0.5 | 77.0 | 86.0 | B | 0.5 | 70.0 | 75.0 |
| C | 1.5 | 82.0 | 90.0 | C | 1.5 | 74.5 | 80.0 |
| D | 3.0 | 84.0 | 93.0 | D | 3.0 | 78.5 | 85.0 |

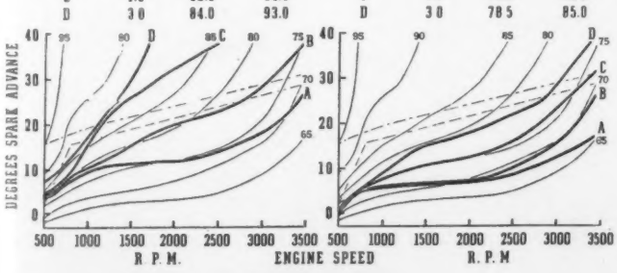


**FIGURE 18**

**Borderline Knock Curves—*Comparison:* Commercially Possible Special Blend, and Present Commercial Base Stock.**

CAR NO. 222, L-HEAD ENGINE, COMP RATIO 8.5 to 1

| FUEL E-5—SPECIAL BLEND | | | | FUEL E-6—PRESENT BASE STOCK | | | |
|---|---|---|---|---|---|---|---|
| | TEL | OCTANE NUMBER | | | TEL | OCTANE NUMBER | |
| FUEL No | ml/GAL | MOTOR | RESEARCH | FUEL No | ml/GAL | MOTOR | RESEARCH |
| A | 0.0 | 71.0 | 81.0 | A | 0.0 | 66.5 | 70.5 |
| B | 0.5 | 77.0 | 86.0 | B | 0.5 | 70.0 | 75.0 |
| C | 1.5 | 82.0 | 90.0 | C | 1.5 | 74.5 | 80.0 |
| D | 3.0 | 84.0 | 93.0 | D | 3.0 | 78.5 | 85.0 |

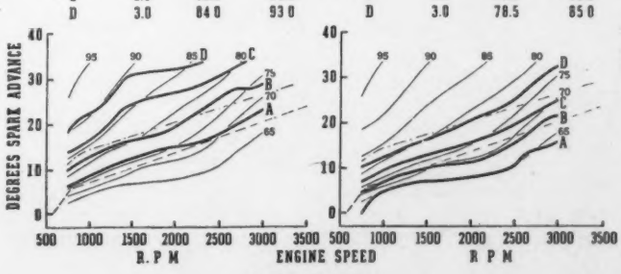


**FIGURE 19**

**Borderline Knock Curves—*Comparison:* Commercially Possible Special Blend, and Present Commercial Base Stock.**

**TABLE 4**

**Fuel Evaluation Based on Tetraethyl-Lead Requirement**

| Engine Type: | ML TEL† PER GAL. TO GIVE MAXIMUM PERFORMANCE | | | | | | | | | ML TEL† per Gal. to Give 94.7 CFR Research Octane No. | ML TEL† per Gal. from 94.7 CFR Research Octane No. to Maximum Power Performance | | ML TEL† per Gal. to Give 82.3 ASTM Motor Octane No. | ML TEL† per Gal. from 82.3 ASTM Motor Octane No. to Maximum Power Performance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L-Head Engines | | | | | Valve-in-Head Engines | | | | | L-Head | Valve-in-Head | | L-Head | Valve-in-Head |
| Car No.: | 208 | 222 | 222 | 222 | 222 | 8486 | 215 | 215 | 215 | .... | 208 | 8486 | .... | 208 | 8486 |
| Compression Ratio: | 8.5 to 1 | 6.9 to 1 | 7.5 to 1 | 8.5 to 1 | 9.4 to 1 | 8.0 to 1 | 6.5 to 1 | 8.0 to 1 | 9.0 to 1 | .... | 8.5 to 1 | 8.0 to 1 | .... | 8.5 to 1 | 8.0 to 1 |
| **"N" Series of Fuels:** | | | | | | | | | | | | | | | |
| N-12 | 3.00+ | .... | .... | .... | .... | 3.00+ | .... | .... | .... | 3.00+ | .... | .... | 3.00+ | .... | .... |
| N-13 | 0.40 | .... | .... | .... | .... | 1.10 | .... | .... | .... | 0.60 | —0.20 | +0.50 | 0.37 | +0.03 | +0.73 |
| N-14 | 2.20 | .... | .... | .... | .... | 2.20 | .... | .... | .... | 2.50 | —0.30 | —0.30 | 0.50 | +1.70 | +1.70 |
| N-15 | 0.30 | .... | .... | .... | .... | 0.90 | .... | .... | .... | 0.50 | —0.20 | +0.40 | 0.60 | —0.30 | +0.30 |
| N-16 | 1.10 | .... | .... | .... | .... | 0.40 | .... | .... | .... | 1.20 | —0.10 | —0.80 | 1.50 | —0.40 | —1.10 |
| N-17 | 0.70 | .... | .... | .... | .... | 0.40 | .... | .... | .... | 0.45 | +0.25 | —0.05 | 0.20 | +0.50 | +0.20 |
| N-18 | 0.70 | .... | .... | .... | .... | 0.70 | .... | .... | .... | 0.00 | +0.70 | +0.70 | 0.35 | +0.35 | +0.35 |
| N-19 | 0.80 | .... | .... | .... | .... | 0.40 | .... | .... | .... | 0.45 | +0.35 | —0.05 | 0.00 | +0.80 | +0.40 |
| N-20 | 3.00+ | .... | .... | .... | .... | 3.00+ | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| N-22 | 2.10 | .... | .... | .... | .... | 1.10 | .... | .... | .... | 3.00+ | .... | .... | 1.95 | +0.15 | —0.85 |
| N-23 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| N-24 | 1.40 | .... | .... | .... | .... | 0.90 | .... | .... | .... | 2.20 | —0.80 | —1.30 | 1.37 | +0.03 | —0.47 |
| N-25 | 3.00+ | .... | .... | .... | .... | 3.00+ | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| N-26 | 3.00+ | .... | .... | .... | .... | 3.00+ | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| N-27 | 1.20 | .... | .... | .... | .... | 0.80 | .... | .... | .... | 1.30 | —0.10 | —0.50 | 1.80 | —0.60 | —1.00 |
| N-28 | 2.20 | .... | .... | .... | .... | 1.60 | .... | .... | .... | 2.70 | —0.50 | —1.10 | 0.90 | +1.30 | +0.70 |
| N-29 | 0.30 | .... | .... | .... | .... | 0.20 | .... | .... | .... | 0.40 | —0.10 | —0.20 | 1.00 | —0.70 | —0.80 |
| **"E" Series of Fuels:** | | | | | | | | | | | | | | | |
| E-1 | .... | 0(10° A)* | 0(6° A)* | 0.10 | 0.45 | 3.00 | 0.10 | 1.40 | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-2 | .... | 0(10° A)* | 0(5° A)* | 0.10 | 0.70 | 2.50 | 0.20 | 3.00 | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-3 | .... | 0( 7° A)* | 0(4° A)* | 0.30 | 2.00 | 3.00+ | 0.30 | 3.00+ | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-4 | .... | 0(10° A)* | 0(6° A)* | 0.10 | 0.75 | 1.00 | 0(4° A)* | 1.50 | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-5 | .... | 0( 3° A)* | 0.20 | 0.90 | 2.30 | .... | 1.30 | 3.00+ | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-6 | .... | 1.10 | 2.00 | 3.00+ | 3.00+ | .... | 3.00+ | 3.00+ | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-7 | .... | 0.75 | 1.80 | 3.00 | 3.00+ | .... | .... | 3.00+ | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-8 | .... | 0.60 | 1.80 | 3.00 | 3.00+ | .... | .... | 3.00+ | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-15 | .... | 0(12° A)* | 0(4° A)* | 0(1° A)* | 1.10 | .... | 0(1° A)* | 1.10 | 3.00+ | .... | .... | .... | .... | .... | .... |
| E-16 | .... | 0(12° A)* | 0(9° A)* | 0(2° A)* | 0.60 | .... | 0(0° A)* | 0.10 | 2.70 | .... | .... | .... | .... | .... | .... |
| E-17 | .... | 0( 0° A)* | .... | .... | 3.00+ | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| E-18 | .... | 0( 0° A)* | 0.50 | 2.80 | .... | .... | 3.00+ | 3.00+ | 3.00+ | .... | .... | .... | .... | .... | .... |

* Degrees A in parenthesis is spark advance above maximum power before knock occurs. † Tetraethyl lead.

nection with the possible commercial manufacture of fuels, it is highly probable that further research would give even better results.

## PART 4

It is difficult to use road test data obtained by the borderline method in the evaluation of fuels from the standpoint of refinery economics. The ideal way to do this would be to compare fuels on the basis of cost to obtain a desired road effect. Such a method is impractical when applied to a large group of fuels, because it is too difficult to estimate accurately the cost of an experimental blend. The following compromise methods have been used in an attempt to get some idea of the comparative economic value of the fuels tested, and the results obtained by these methods are shown in Table 4:

1. The evaluation of fuels based on the amount of tetraethyl lead that must be added to each clear fuel to satisfy the maximum-power-spark-advance requirements of the test car at the speed of maximum knock based on research-method values.
2. The evaluation of fuels based on the amount of tetraethyl lead that must be added to each clear fuel to

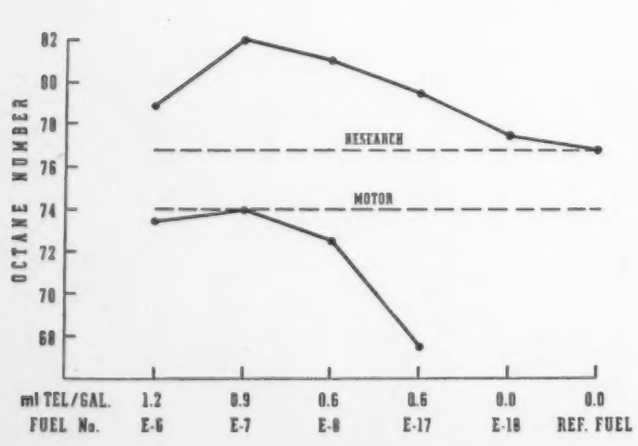


**FIGURE 20**

**Correlation Between Actual Road Requirement for Maximum-Power Spark Timing and Laboratory Motor- and Research-Method Values for Test Fuels.**

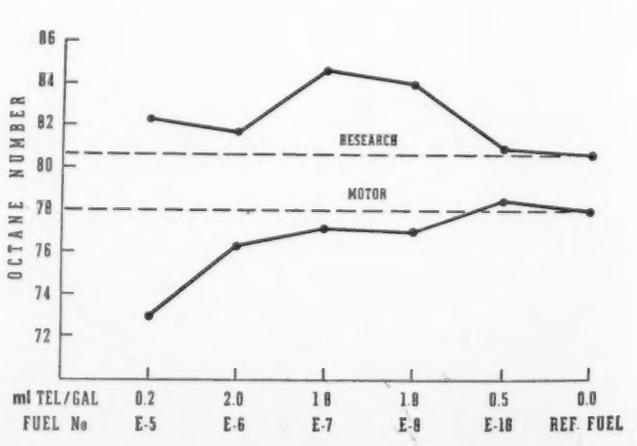


**FIGURE 21**

**Correlation Between Actual Road Requirement for Maximum-Power Spark Timing and Laboratory Motor- and Research-Method Values for Test Fuels.**

satisfy the maximum-power-spark-advance requirements of the test car at the speed of maximum knock based on research-method values.

3. The evaluation of fuels based on the amount of tetraethyl lead that must be added, or deducted, from each fuel to satisfy the maximum-power-spark-advance requirements of the test car at the speed of maximum knock after all of the fuels have been leaded arbitrarily to the same motor-method octane number.
4. The evaluation of fuels based on the amount of tetraethyl lead that must be added, or deducted, from each fuel to satisfy the maximum-power-spark-advance requirements of the test car at the speed of maximum knock after all of the fuels have been leaded arbitrarily to the same research-method octane number.

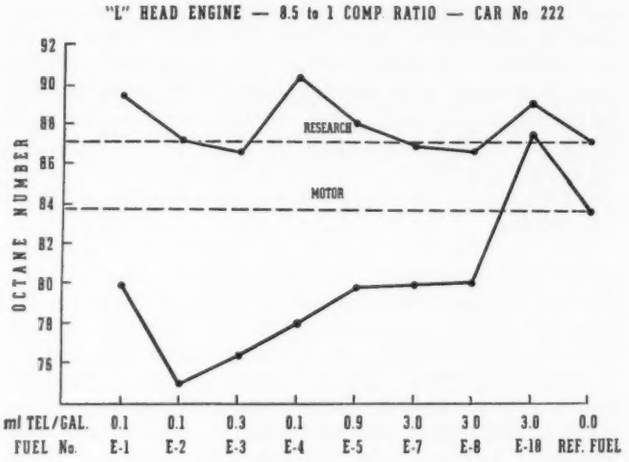


**FIGURE 22**

**Correlation Between Actual Road Requirement for Maximum-Power Spark Timing and Laboratory Motor- and Research Method Values for Test Fuels.**

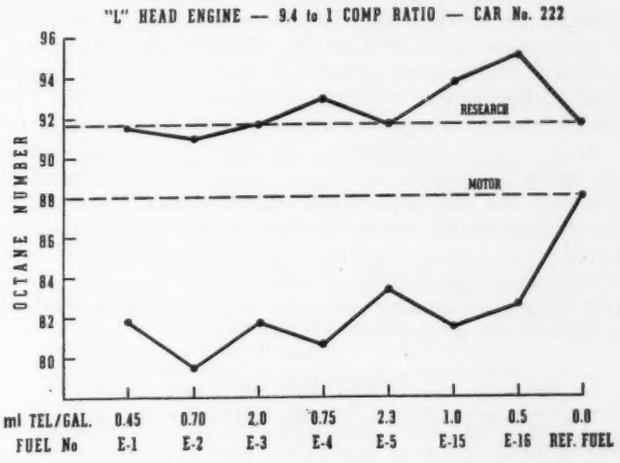


**FIGURE 23**

**Correlation Between Actual Road Requirement for Maximum-Power Spark Timing and Laboratory Motor- and Research-Method Values for Test Fuels.**

The fuel evaluations all have been based on the maximum-power-spark-advance curves of the test engines, because no distributor curves are available for the higher compression-ratio heads. As one car was equipped with a fluid drive, it was impossible to obtain ratings in it below 800 rpm; and, for this reason, all of the comparisons have been made at speeds above this.

By methods 1 and 2, the fuels requiring the least amount of lead are rated as the best in the series, but these methods do not take into consideration the fact that all of the clear fuels do not have the same "motor" and "research" octane numbers. Such a method, therefore, tends to penalize the fuels having the lowest clear "motor" or "research" octane number. Methods 3 and 4 were devised in an attempt to minimize this effect, and are preferable to 1 and 2, as the error in evaluation now has been reduced to the differences between the lead susceptibilities of the fuels under consideration.

The problem of fuel evaluation would be simplified greatly if some means could be found of correlating laboratory motor- and research-method values with road anti-knock performance. From these borderline data, correlation as usually considered, i.e., direct comparison between road and laboratory octane numbers of the test fuel, could not be obtained. Instead, the amount of tetraethyl lead required in the test fuel to satisfy the maximum-power-spark-advance requirement of the engine at the point of maximum knock was obtained by interpolation from the fuel borderline curves. Both "motor" and "research" octane numbers of the test fuel containing this amount of lead then were obtained directly from the laboratory lead-susceptibility curves. If correlation were perfect, all fuels which satisfied a given engine should have the same "motor" or "research" octane values.

The results obtained for the "E" series of fuels are shown graphically in Figures 20 through 23. The points of the jagged curves represent the laboratory octane numbers for each test fuel, and the dotted line represents the reference-fuel octane requirement of the test car, by either motor- or research-method calibration, as indicated. Inasmuch as the results for both the cars were quite similar, only the data obtained using the L-head engine at four different compression ratios are shown. It will be noted that neither the "motor" nor the "research" octane values alone, or in combination, gave a reliable indication of possible road behavior. It is interesting, however, that as the compression ratio is increased, the correlation of the road results with the laboratory "research" octane values becomes increasingly better, whereas the correlation with the motor-method values becomes increasingly worse.

Throughout this work, the consideration of the hydrocarbon analysis of a fuel in conjunction with its "motor" and "research" octane values has seemed to offer the best means of correlating road performance with laboratory data. As shown in Tables 2 and 3, all of the fuels in the "N" and "E" series were cut into either two or three fractions with respect to boiling range, and each fraction analyzed separately for its content of aromatics, naphthenes, paraffins, and olefins. These tests have shown that any fuel containing large portions of olefinic material throughout the boiling range will tend to knock at high engine speeds, and will have relatively poor lead susceptibility not only in the laboratory, but on the road. A highly sensitive fuel, however, in which the high-boiling olefins have been replaced with heavy paraffinic, aromatic, or naphthenic material will show considerably better high-speed performance and considerably better road lead suceptibility. Fuels containing large amounts of paraffinic material in the light-boiling range, in general, will have poor low-speed anti-knock performance and poor lead susceptibility at low speeds; but if the low-boiling paraffins are replaced with light olefinic and/or aromatic material,

low-speed anti-knock performance and low-speed road lead susceptibility usually will be improved. Although sufficient data are not available to permit the formulation of any quantative procedure for predicting fuel road performance, the method outlined above does give reasonably accurate qualitative indications. Perhaps better correlation could be obtained if consideration were given to the "motor" and "research" octane values of the various fractions of a fuel obtained by simple distillation.

### Conclusions

In this paper, the authors have attempted to summarize the work which has been carried out in their laboratories since 1938 on the effect of chemical composition on the road anti-knock performance and road lead susceptibility of fuels. Because of the great extent of the problem, no phase of it can be said to have been explored completely. The results so far obtained do seem to justify more extended research. Several possibilities for improving present-day fuels and for producing better fuels for the future have been indicated. It is hoped that the examples herein given will stimulate wider interest in the possibilities of producing improved motor fuels by coordinating chemical composition with road behavior.


### Acknowledgment

The authors wish to make the following acknowledgments:

To Ethyl Gasoline Corporation for help in obtaining much of the road-test data on which this paper is based.

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To Messrs. K. Boldt, A. B. Wilder, G. Annable, W. J. Hudson, F. C Minor, and F. L. Mueller of The Pure Oil Company for their excellent cooperation in carrying out both the road and laboratory tests.


## APPENDIX "A"

### Method of Determining the Composition of Gasoline

The method used to determine the hydrocarbon composition of the test fuels, i.e., their content of paraffins, naphthenes, olefins, and aromatics, was essentially that proposed by Kurtz and Headington,[6] with slight modifications. The procedure requires that the gasoline be cut into three fractions: initial boiling point to 140° F., 140° to 235° F., and 235° F. to the end point. The bromine number of the initial-boiling-point-to-140° F. fraction is determined according to the Francis method,[7] and the refractive index and specific gravity determined at 20° C. This fraction does not contain aromatics, so that from these data the percentage of paraffins, naphthenes, and olefins can be calculated according to the method of Kurtz and Headington based upon the specific gravity and refractivity intercept.

The 140°-to-235°-F.-to-end-point fractions are treated separately in a similar manner: 400 ml of the sample is placed in a liter separatory funnel and 400 ml of 87-percent sulphuric acid is added in small volumes. The funnel is shaken vigorously for 10 minutes under a stream of cold water, and the sample then is allowed to stand for one hour, after which the acid layer is withdrawn. The hydrocarbon layer then is treated in a similar manner with 98-percent sulphuric acid; and, after withdrawal of the acid layer, is water-washed, neutralized with a 10-percent solution of sodium hydroxide, water-washed again, and distilled to 10° F. above the original end point of the sample.

The material lost during treatment represents the olefins and aromatics, and the material distilled represents the paraffins and naphthenes present in the original sample. By comparing the specific gravity and refractivity intercept of the material lost and the material recovered with similar properties of the pure hydrocarbons within the boiling-point range of the sample, the percentage of paraffins, naphthenes, olefins, and aromatics in the original sample may be calculated.

As the fuels investigated in the present work were all finished, treated fuels, their content of conjugated diolefins was considered to be negligible, and no attempt was made to correct the value reported for the olefin content.

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# New Lubricating-Oil-Decolorizing And Clay-Reactivating Process

W. B. CHENAULT and A. E. MILLER
Sinclair Refining Company

**THE clay treatment of lubricating-oil stocks consists of a coordinated series of continuous operations whereby oils are decolorized and the used clay reactivated to high efficiency by extraction with solvents.**

**Oil is contacted with clay in the presence of naphtha and traces of acetone at temperatures high enough to utilize the clay efficiently and to insure removal of the naphtha and acetone, but not high enough to affect adversely the nature of the coloring matter adsorbed in the clay so that its reactivation with solvents becomes difficult or impossible.**

**The process yields finished oils meeting flash, color, and viscosity specifications without further processing. The clay is handled, in the form of a slurry or cake with oil or naphtha, in the various steps of this process.**

**The complete process is a closed system, and a flue-gas atmosphere is provided during certain operations and in certain pieces of equipment to avoid incidental oxidation and danger of explosion or fire.**

**The process handles all grades of stocks, and the change-over from one stock to another is simple. The process as now carried out has been in commercial operation since June, 1940, resulting in substantial savings in clay-treating costs.**

**This paper was presented to Division of Refining, before Twenty-Second Annual Meeting of the American Petroleum Institute, at San Francisco, November 6, 1941.**

THE treatment of lubricating oils by contacting them with decolorizing adsorbent clays has been practiced for at least 70 years, and many kinds of clays or clay-like substances have been used for this purpose. Almost from the first, the users of such decolorants have sought to reactivate the spent clays for reuse.

The method most widely used for reactivating spent decolorizing clays is that of burning. No description of this type of clay reactivation is necessary herein. This method has been applied most successfully to granular fuller's earth and bauxite and, in a few cases, with some degree of success, to certain decolorizing clays in the form of powders.

The principal other method for reactivating spent decolorizing clays is that of solvent extraction. Briefly stated, this consists of removing from the spent clay, by means of suitable solvents, the coloring matter adsorbed by the clay when decolorizing the oil.

When the relatively high-priced acid-improved clays and synthetic clays were introduced on the market, there was an added incentive to find means for reactivating such clays, when spent, whereby they might be restored to a high percentage of their original efficiency. Inasmuch as most of these latter clays were used in powder form and had a delicate structure which might be injured by burning or the usual heat treatment, great efforts were made to reactivate them by means of solvents. The widespread interest in this field is testified to by various investigators in the period from 1900 to date, wherein many processes were suggested and numerous solvents recommended. We believe that very few of these methods ever were developed beyond the laboratory stage.

Our purpose in presenting this paper is to describe a process which is operating commercially at our Wellsville, New York, refinery, where the details of the process were developed. This process consists of continuously decolorizing lubricating oils with clay, combined with a continuous reactivation of the spent clay by extraction with suitable solvents.

All lubricating-oil stocks at Wellsville are clay-treated in the same manner, and in all cases the spent clay is reactivated. The oil is contacted with the clay, in the presence of a substantial quantity of naphtha, at temperatures just high enough to utilize the clay efficiently and to permit removal of the naphtha, but not high enough to modify the nature of the coloring matter adsorbed in the clay so that its reactivation with simple solvents becomes difficult or impossible. We use Magnesol as the decolorizing clay because of its high decolorizing efficiency with our oils at moderately elevated temperatures, and because it can be reactivated repeatedly to high efficiency with simple solvents.

The naphtha used is the regular "300/400" plant grade, and the color solvent is a blend consisting of about 45 percent by volume of acetone and 55 percent naphtha. Although the oils are contacted in naphtha dilution, the process yields oils meeting flash, color, and viscosity specifications without further processing.

Except when first introduced into the system, clay never is handled as a dry powder. Both new and reactivated clays are handled, in the form of a slurry or cake with oil or naphtha, in the various steps of this process. When it becomes desirable to renew the clay charge, the old clay is discarded from the system with enough moisture so that it will not dust.

The complete decolorizing and the clay-reactivating process constitutes a closed system. Therefore, no air, moisture, nor other disturbing influences interfere with obtaining the best results—a condition which favors low naphtha and low color-solvent losses. The process is free from incidental oxidation

and danger of explosion or fire, because a flue-gas atmosphere is provided for the system as described hereinafter.

**Description of the Lubricating-Oil - Decolorizing and Clay-Reactivating Process as Practiced at Wellsville**

Figure 1 is a simplified flow diagram of the process.

The raw-oil stock, heated to a temperature of from 190 to 200° F., is introduced into mixing tank **1.** Here it is blended with reactivated clay in the form of a naphtha slurry, containing some recycle oil which returns in the form of high-oil-content filtrate from the primary deoiling filter. Mixing tank **1,** which is also the heater feed tank, is a closed-type steel tank provided with a mechanical stirrer, closed steam coils for temperature control, and a flue-gas atmosphere.

The mixture of oil, naphtha, and reactivated clay in feed tank **1** is pumped to pipe-still heater **2** oper-

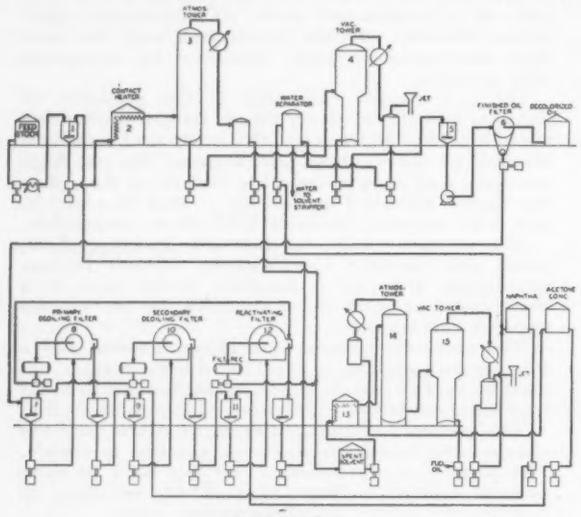

**FIGURE 1**
**Flow Diagram of the Lubricating-Oil - Decolorizing and Clay-Reactivating Process.**

ating at an outlet temperature of 400 to 415° F. Figure 2 shows the heater feed pumps, and Figure 3 the pipe-still heaters, usually referred to as contact heaters. The charge then is flashed in a distillation system (see Figure 4), consisting of an atmospheric tower **3** and a vacuum tower **4,** in order to remove the naphtha diluent. In the atmospheric tower, an average temperature of 400° F. is held at the top and of 402° F. at the bottom; about half of the naphtha and substantially all of the small amount of acetone contained in the charge are removed as an overhead product. This overhead is rerun to recover its acetone content. The bottoms from the atmospheric tower are pumped to the vacuum tower **4,** which operates at from 20 to 22 inches of mercury, gage. In addition, steam is introduced into the bottom of the vacuum tower to assist in stripping the last traces of naphtha from the oil. The temperature in this tower will average 368° F. at the top and 370° F. at the bottom, and the tower yields an overhead product consisting of naphtha and water, which overhead passes through a condenser to a receiver and finally to a separator. As the water contains a small percentage of acetone, it is sent to the solvent-recovery unit, while the naphtha goes to regular tankage.

No naphtha is required for refluxing in either tower of the flash system; but there is introduced continuously, into the top of each tower, a small quantity of the oil being decolorized, in order to avoid possible accumulation of clay on the trays. Figure 5 is a view showing the pumps that handle the bottoms from the atmospheric and vacuum towers of the naphtha flash system.

The bottom product from the vacuum tower, consisting of a suspension of clay in naphtha-free decolorized oil, is pumped to the filter feed tank **5.** This tank is of the closed type, provided with a mechanical stirrer and a flue-gas atmosphere. The clay-oil mixture is pumped to four finished-oil filters **6.** These filters discharge the decolorized oil (which flows

**FIGURE 2**
**Heater Feed Pumps**

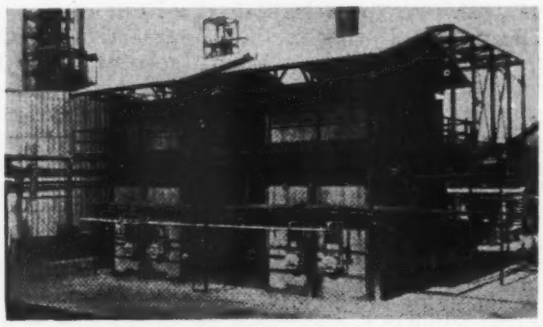

**FIGURE 3**
**Contact Heaters**

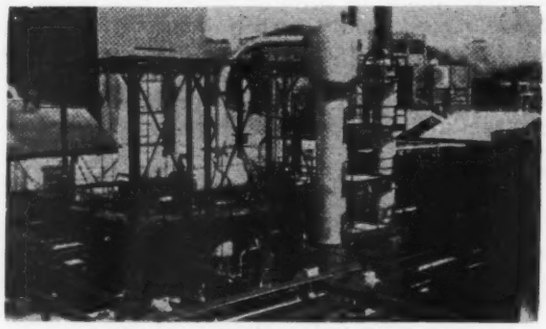

**FIGURE 4**
**Naphtha Flash System after the Contact Heaters**

through blotting-paper filter presses to finished-oil storage) and a clay cake, wet with oil, which passes to the subsequent reactivating operation.

The finished-oil filters are operated in a manner normal to this type of equipment; but at the end of the oil run, after a cake of ½ to ¾ inch in thickness has been built on the leaves, it is blown for 5 to 7 minutes to displace most of the oil. The average cycle

on these filters is about 30 minutes including the foregoing flue-gas blow and 3 minutes for dumping. This produces a clay cake consisting of about 55 percent oil and 45 percent clay by weight, which cake readily falls free from the filter leaves into a hopper. Figure 6 shows the pumps, conveyors, and hoppers below the finished-oil filters. Then the clay cake is slurried with sufficient naphtha so that it can be pumped to mixing tank **7**, which constitutes the feed to the first deoiling filter. This filter feed tank is also of the closed type,

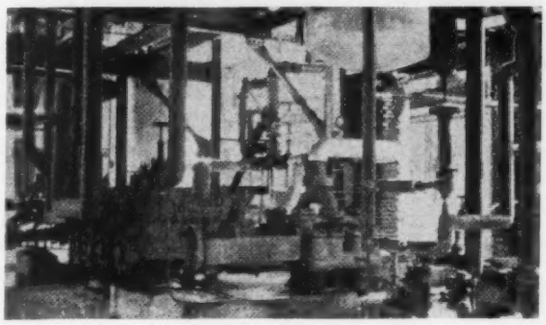

**FIGURE 5**
**Pumps on Atmospheric and Vacuum-Tower Bottoms—Naphtha Flash System.**

**FIGURE 6**
**Pumps, Conveyors, and Hoppers below Finished-Oil Filters**

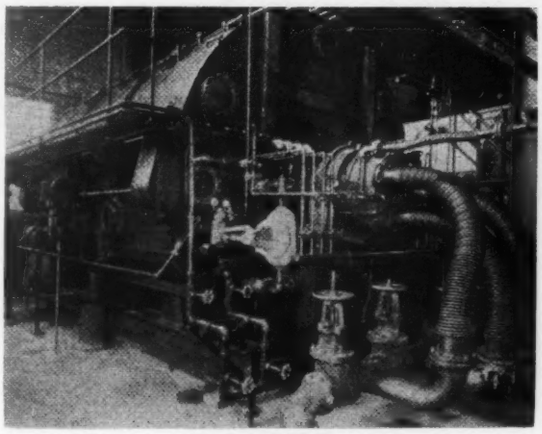

**FIGURE 7**
**Continuous Rotary Vacuum Filter**

provided with a mechanical stirrer and maintained under a flue-gas atmosphere. It contains a mixture of spent clay, oil from the clay cake, and naphtha.

In our present operation, we use two deoiling filters and one reactivating filter (**8, 10** and **12,** respectively, of Figure 1). These filters are all of the same size and design and are, in fact, interchangeable. Figure 7 is a front view of one of these continuous vacuum filters. They are continuous rotary-drum type vacuum filters designed especially for this process. They are similar in many respects to those used in solvent-dewaxing plants, the principal differences being in the design of the sprays for washing the clay cake, in the method of collecting filtrates, and in the provision of mechanical agitators in the filter tanks. When handling clay used in treating highly viscous oils, such as raffinates from cylinder stocks or straight cylinder stocks, the mixture in **7** is heated to a temperature of from 180 to 185° F.; but, when working with clay from neutral oils, the temperature is held at 170 to 175° F. This warm slurry from filter feed tank **7,** which may carry from 15 to 18 percent by weight of clay, is pumped to the tank of the primary deoiling filter **8.** The agitator in the filter tank keeps the clay in suspension. A layer of clay cake builds up on the rotating filter drum to a thickness averaging from 3/16 to ¼ inch; and, as the drum rotates and the clay cake emerges from the liquid, it is washed with naphtha supplied from spray nozzles. A vacuum of from 10 to 20 inches of mercury, gage, is maintained in the filter drum sections, and an atmosphere of flue gas under a pressure of 5 inches of water is maintained in the filter hood. The partly deoiled clay is removed from the filter drum by "back blowing" with flue gas, under a pressure of approximately 4 pounds, just ahead of the scraper blade. The clay cake, which consists of about equal parts by weight of clay and naphtha, drops into a scroll—which delivers it to a naphtha slurry tank.

The oil washed from the clay cake by the naphtha is collected in filtrate receivers. The filtrate from filter **8** carries about 25 percent by volume of oil, and this is returned to heater feed tank **1**; but, on the way, it is used to assist in removing the clay cake from the scroll of the reactivating filter **12.**

The oil content of the clay cake from filter **8** averages from 1.5 percent when the plant is running on raffinate to about 3.5 percent when running neutrals. It is slurried with naphtha and introduced into mixing tank **9,** which feeds the second deoiling filter. The feed is adjusted with naphtha so that the clay content will range from 20 to 26 percent, averaging 25 percent to make a pumpable mixture. This usually is delivered to the second deoiling filter **10** at a temperature of from 100 to 110° F. The wash naphtha is applied to the deoiling filters at an average temperature of about 150° F.

The products from the second deoiling filter are: a clay cake consisting of about equal parts by weight of naphtha and clay, in which the oil content averages filtrate consisting of naphtha carrying about 1 percent of oil. The filtrate from the second deoiling filter, on account of its low oil content, is used partly for washing the clay cake in the primary deoiling filter and partly on the scroll of the secondary deoiling filter to slurry the deoiled clay cake.

The deoiled clay cake, slurried with naphtha, is introduced into mixing vessel **11.** This, as well as filter feed tanks **7** and **9,** is a closed steel tank provided with a mechanical stirrer and a flue-gas atmosphere. Figure 8 shows the type of mixing tanks used for feeding the deoiling and reactivating filters. This is known as the extractor, and is also the feed tank for the reactivating filter **12.** The color solvent, at present a blend of acetone and naphtha, respectively, is added to the naphtha-clay slurry at this point. The average acetone content of the charge in **11** is 19 to

20 percent by volume of the liquid portion; and this charge, which carries from 11 to 14 percent by weight of clay, is delivered to the tank of the reactivating filter **12** at a temperature ranging from 90 to 100° F. Fresh naphtha at 90° F. is used in washing the clay cake on the reactivating filter drum.

The reactivating filter is, in all respects, a duplicate of and operated in a manner similar to the deoiling filters. The filter hood is supplied with low-pressure flue gas and a moderate vacuum of from 10 to 15

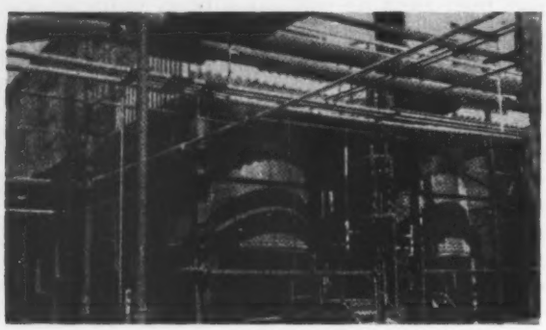

**FIGURE 8**
**Slurry Tanks for Feed to Deoiling and Reactivating Filters**

inches carried in the filter drum sections. The clay cake from the reactivating filter will contain about 0.35 percent by weight of oil and a small amount of acetone. Filtrate from the primary deoiling filter is used on the scroll of the reactivating filter to assist in removing the clay cake, and to make a slurry which then is returned to heater feed tank **1.** The filtrate from the reactivating filter, consisting mostly of naphtha, but carrying the coloring matter removed from the clay, and containing on an average of 12 to 15 percent of acetone, goes to the solvent-recovery unit. Figure 9 is a view through the pump room below the filter floor. This shows the pumps and receivers handling filtrate and slurry from the rotary filters.

There are two separate and distinct flue-gas systems used at the clay-contacting and -recovery unit. The first consists of straight flue gas substantially free from oxidizing gases and free from all naphtha or acetone. This is used at a pressure of 50 pounds for blowing the finished-oil filters, and at gas-holder pressure to supply a non-oxidizing atmosphere wherever the naphtha-free decolorized oil is maintained at elevated temperatures in any part of the system such as, for instance, in the filter feed tank **5.**

In the second system, flue gas at a pressure of 5 pounds supplies a non-oxidizing atmosphere in the hoods of the rotary filters, mixers, tankage, and in all steps of the process where naphtha or acetone is present. It is also used for blowing the clay cakes from the rotary filter drums. This is a recirculating system, in which the flue gas recirculates between a gas holder

**FIGURE 9**
**Pumps and Receivers Handling Filtrate and Slurry from Rotary Filters.**

and the various pieces of equipment where it is used. The flue gas, from blowing back the clay cake from the reactivating filter, is pumped from the filtrate receivers, cooled, and then passed through a packed tower in which it is scrubbed with fresh naphtha. The naphtha, which absorbs most of the acetone, is passed to the solvent-recovery unit. The flue gas, containing small percentages of naphtha and acetone, goes to a gas holder. Figure 10 is a view showing the coolers, scrubbers, and gas holder for the flue gas from the rotary vacuum filters.

The solvent-recovery unit, shown in Figure 11, consisting of a pipe-still heater **13,** an atmospheric tower **14,** and a vacuum tower **15,** originally was designed for the rerun of cracked distillate. It was modified so that it would separate a concentrate of acetone and naphtha from a charge consisting of about 89.5 percent naphtha, 9 percent acetone, and the balance 1.5 percent of heavy residual oil containing the coloring matter removed from the spent clay

**TABLE 1**
**Yield Figures, Charge to Solvent-Recovery Unit**

| | Barrels Per Day | Gravity (° A.P.I.) | Acetone (Percent) | Charge (Percent) |
|---|---|---|---|---|
| Atmospheric overhead (acetone concentrate) | 499 | 55.0 | 45.000 | 20.5 |
| Vacuum overhead (naphtha) | 1,825 | 53.0 | 0.008 | 75.0 |
| Vacuum bottoms | 109 | 27.4 | None | 4.5 |
| Average daily charge | 2,433 | 53.5 | 9.000 | 100.00 |

**Yield Figures, Rerun of Vacuum-Tower Bottoms**

| | Barrels Per Day | Gravity (° A.P.I.) | Charge to Rerun Still (Percent) | Charge to Solvent-Recovery Unit (Percent) |
|---|---|---|---|---|
| Overhead (heavy naphtha) | 70 | 50.8 | 64.00 | 2.88 |
| Light gas oil | 3 | 32.0* | 2.88 | 0.13 |
| Intermediate gas oil | 3 | 29.8* | 2.88 | 0.13 |
| Heavy Fuel | 33 | 18.4 | 30.24 | 1.36 |
| Vacuum-tower bottoms | 109 | 27.4 | 100.00 | 4.50 |

* On a naphtha-free basis.

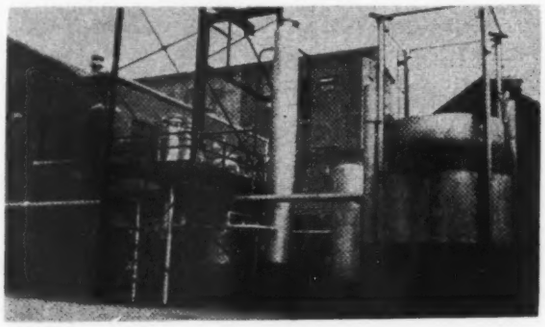

**FIGURE 10**
**Flue-Gas Scrubber, Holder, and Coolers**

during its reactivation. It is possible with this unit to produce a concentrate of from 42 to 45 percent of acetone in naphtha. This concentrate, produced as an overhead product from the atmospheric tower, goes to tankage as the solvent for the solvent extraction of the deoiled used clay. The balance of the naphtha, which is recovered as an overhead product

from the vacuum tower, goes to naphtha storage. The bottoms from the vacum tower, amounting to 4.5 percent of the charge to the unit, contain about 64 percent of heavy naphtha. This is recovered by rerunning the vacuum-tower bottoms in one of the conventional refinery stills. The ultimate bottoms from this unit go to heavy fuel. The average charge to the solvent-recovery unit is 2433 barrels per day. This charge yields the following products: acetone-naphtha concentrate overhead from the atmospheric tower, 20.5 percent; naphtha overhead from the vacuum tower, 75 percent; and vacuum-tower bottoms rerun charging stock, 4.5 percent. The ultimate heavy fuel from the rerunning of the vacuum-tower bottoms amounts to 30.24 barrels per day, or 1.36 percent of the charge to the recovery unit. It contains the tarry adsorbed coloring matter removed from the oil during the decolorizing operation by the clay, and which was removed from the used clay in the clay-recovery operation. This final heavy fuel has a flash point of 450° F., and a Saybolt Universal viscosity of 180 seconds at 210° F.

Table 1 shows the yield of products from the solvent-recovery distillation unit and from the rerunning of the vacuum-tower bottoms therefrom:

In Table 2 are shown 100-ml. ASTM distillations

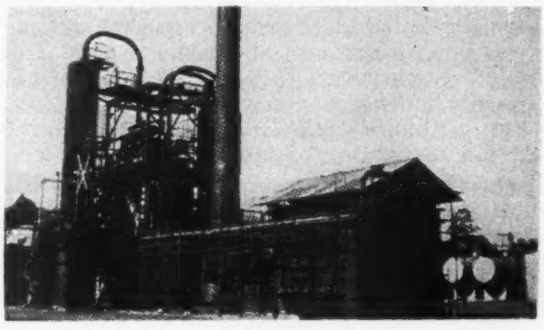

**FIGURE 11**
**Spent-Solvent Rerun Unit**

of the products from the solvent-recovery unit. Note that the naphtha constituting the overhead from the vacuum tower has substantially the same boiling characteristics as the normal plant "300/400" naphtha used throughout the process, its initial boiling point being 270° F., and its end boiling point being 363° F. It contains only a trace of acetone. Refer, in this connection, to that portion of this paper dealing with "oil diluents."

It must be borne in mind that the unit just described is the first of its kind, and that the equipment used in many instances was adapted from an older type of contact filtration plant. In case a new unit of this type were built, it could be simplified considerably and made more compact—which would result in easier and more economical operation, lower labor costs, as well as lower solvent losses. Among advantageous changes that could be made in equipment might be cited the provision of a solvent-recovery unit, designed and built for the purpose of producing acetone-naphtha blends of any desired acetone concentration. Another decided improvement would be the substitution of a continuous-type filter for separating the finished oil from the used clay. Pieces of equipment also could be grouped more conveniently in a completely new plant, with shorter lines and with all tankage for solvent storage built of a type designed specifically for that purpose. It is to be pointed out that, although two deoiling filters are used in the Wellsville installation, only one of the proper size and design would be required in a new installation.

A number of questions naturally arise in connection with a new process of this type, and we shall endeavor to answer a few of those which have been raised frequently.

**TABLE 2**
**100-Ml ASTM Distillations: Products from the Solvent-Recovery Unit**

| | SOLVENT-RECOVERY UNIT | | | |
|---|---|---|---|---|
| | Atmospheric Overhead Acetone Concentrate | Vacuum Overhead (Naphtha) | Vacuum Bottoms | Rerun Unit Overhead Heavy Naphtha |
| Gravity (° A.P.I.) | 55.0 | 53.0 | 27.4 | 50.8 |
| Initial boiling point (° F.) | 120 | 270 | 370 | 276 |
| 10 percent point | 127 | 288 | 474 | 300 |
| 20 percent point | 130 | 290 | 566 | .... |
| 30 percent point | 132 | 295 | 626 | .... |
| 40 percent point | 134 | 298 | 678 | .... |
| 50 percent point | 140 | 302 | 720 | .... |
| 60 percent point | 158 | 308 | 745 | .... |
| 70 percent point | 242 | 312 | 760+ | .... |
| 80 percent point | 268 | 319 | ... | .... |
| 90 percent point | 289 | 330 | ... | 380 |
| End point | 328 | 363 | ... | 540 |
| Acetone (percent) | 45.0 | 0.008 | None | None |
| Charge to solvent-recovery unit (percent) | 20.5 | 75.0 | 4.5 | 2.88 |

## Applicability of the Process

At Wellsville at least 7 different grades of oils, varying from 150 neutral with a Saybolt Universal viscosity of about 145 seconds at 100° F., to heavy raffinates having a viscosity of about 240 seconds at 210° F., regularly are treated by this process. Table 3 gives the typical physical tests on three of such stocks regularly processed at Wellsville. Tests are shown both for the raw and treated stocks. Under each stock is shown also the average percentage of reactivated clay by weight, dry basis, used in decolorizing the stock. The reactivated clay has an average efficiency of from 80 to 85 percent of that of the new clay decolorizing efficiency.

The quantity of clay in the system is practically

**TABLE 3**
**Typical Physical Tests**

| | 150 No. 3 Neutral | | Bright Stock | | Heavy Bright Stock | |
|---|---|---|---|---|---|---|
| | Raw | Treated | Raw | Treated | Raw | Treated |
| Gravity ° A.P.I. | 30.0 | 30.1 | 25.7 | 26.5 | 25.2 | 26.0 |
| Flash point (Cleveland open cup), ° F. | 405 | 405 | 550 | 550 | 610 | 610 |
| Fire point (Pensky-Martens), ° F. | 405 | 405 | 520 | 520 | 555 | 555 |
| Fire point (Cleveland open cup), ° F. | 465 | 460 | 625 | 625 | 690 | 690 |
| Viscosity (Saybolt Universal) at 100° F., seconds | 149 | 145 | ..... | ..... | ..... | ..... |
| Viscosity (Saybolt Universal) at 210° F., seconds | 42.5 | 42.5 | 164 | 160 | 245 | 230 |
| Pour point, ° F. | 15 | 15 | 10 | 10 | 15 | 15 |
| Color, optical-density (Duboscq) | ..... | ..... | 1575 | 515 | 1750 | 575 |
| Color, N.P.A. | 4+ | 2½+ | ..... | 8— | ..... | 8 |
| Carbon residue, percent | ..... | 0.015 | 1.30 | 1.20 | 1.52 | 1.33 |
| Reactivated clay, percent by weight | 4.3 | | 9.5 | | 9.6 | |

constant, so that the throughputs of various grades of oils depend upon the percentage of clay required to decolorize the stock to specification; and this, in turn, depends upon the efficiency of the clay. As much as 4400 barrels per day of neutral and 2000 barrels per day of regular raffinate have been put through this plant. In no case has it been found difficult completely to remove the naphtha from the charge in the flash system so that the finished oil would meet the required flash and viscosity specifications. This was true, even in the case of heavy raffinates having a flash point of 610° F. Although the commercial application of this process has been limited exclusively to Pennsylvania oils, laboratory results have shown that it is also applicable to the lubricating-oil stocks from other crude-oil sources.

### Clays Suitable for This Type of Operation

Any clay to be suitable for the type of operation carried out at Wellsville should have certain characteristics. It should have high oil-decolorizing efficiency at relatively low or only moderately elevated temperatures. Preferably, the coloring matter adsorbed out of the oil by the clay should remain present in the clay in such a condition that it can be displaced and dissolved in simple solvents; in other words, it should not be cracked nor otherwise affected by heat or other agencies in such a way that it becomes difficult to remove from the clay by extraction with such solvents. We, at present, use the clay known as Magnesol, which is a synthetic product and chemically might be designated as a very pure form of hydrous magnesium silicate.

This clay is supplied in 50-pound paper bags, and has a screen test ranging as folows:

| | |
|---|---|
| Percent on 100-mesh | 46.0-36.0 |
| Percent on 200-mesh | 21.6-13.4 |
| Percent on 300-mesh | 21.4-12.0 |
| Percent through 300-mesh | 11.0-38.6 |

The free moisture content varies from 11 to 19 percent, averaging about 15 percent; and the combined moisture is about 7 percent. It has a very slight alkaline reaction, the pH value averaging about 7.3. It weighs about 23 pounds per cubic foot.

The number of times any one charge of clay can be used in the Wellsville commercial unit depends upon its decolorizing efficiency. As the efficiency drops, it becomes an economic question of either replacing the clay charge with a new one or operating the plant under reduced throughputs. We have found it desirable to use clay through about 15 cycles as, with this much use, the efficiency averages 80 to 85 percent of that of the new clay. There have been instances, in our commercial operation, when we have reused the clay 29 times. The average throughput of charging stock of all grades of oil is 1030 barrels per ton of new decolorizing clay. This average figure has at times been as high as 1700 barrels per ton, but it necessarily varies depending upon the type of oil being run and also upon the number of times the clay has been reused.

Clay requirements are calculated on a dry basis, i.e., a correction is made for the percentage by weight of hydrocarbons and free moisture contained in the clay. Our new clay is considered to have a decolorizing efficiency of 100 percent; and, knowing the quantity of new clay required to treat any given oil stock to the desired color, the efficiency of reactivated clay can be determined by establishing the amount required to obtain the same color on the same oil. The optical-density colors taken on the Duboscq colorimeter are used in determining clay efficiencies due to the accuracy with which colors can be taken by this method.

New clay is introduced into the system by charging it into the heater feed tank **1** from a storage bin through automatic weighing and dumping scales. The moisture in the new clay charge is flashed off in the atmospheric tower. While the unit is being charged with new clay, no reactivated slurry is added to the heater feed tank, because the used clay in the system is being removed at the same time from the secondary deoiling filter. By introducing new clay and removing used material at the same time, there is no loss of throughput, because oil is being decolorized continuously.

The clay to be rejected, coming from the secondary deoiling filter in slurry form with naphtha, is pumped to separate filters, where it is steamed to remove and recover the naphtha. The filters are air-blown to dry the cake slightly, but the clay is dumped with enough moisture to prevent a dusty condition. This rejected clay can be brought back to a relatively high decolorizing efficiency by the use of somewhat more color solvent than normally used.

### Oil Diluents

After experimenting with various types of oil diluents, we concluded that Pennsylvania crude naphtha, having a boiling range of about 260 to 380° F., and composed essentially of saturated paraffinic and naphthenic hydrocarbons, was best suited for the purposes of this process. Following is a typical 100-ml. ASTM distillation of such a naphtha:

| | |
|---|---|
| Gravity (° API) | 53.5 |
| Initial boiling point (° F.) | 262 |
| 10-percent point | 280 |
| 20-percent point | 288 |
| 30-percent point | 294 |
| 40-percent point | 299 |
| 50-percent point | 302 |
| 60-percent point | 306 |
| 70-percent point | 308 |
| 80-percent point | 312 |
| 90-percent point | 320 |
| End point | 372 |

We use this grade of naphtha in making up the various clay slurries, for washing the clay cakes on the three rotary vacuum filters, and whenever dilution with naphtha is necessary. For naphtha to be suitable for use in this process, it should have substantially no solvent action toward the coloring matter in the spent clay, particularly during the deoiling step of the clay-reactivating process. Even if too much of this type of naphtha is used, the last increment of oil removed will be darker in color than the charging stock. The maximum amount of wash naphtha allowable is 0.85 gallon per pound of clay.

### Color Solvents

We tested and experimented with a great many different types of solvents during the development of this process, but it was concluded that certain ketones and the lower-boiling alcohols are the most suitable for extracting the coloring matter from the used clay in the Wellsville unit. Acetone is the solvent employed at present, but there is no reason why we could not use methyl ethyl ketone, or one of the lower-boiling alcohols, or a mixture of ketone and alcohol. These solvents are used in admixture with naphtha so that a typical color solvent would be one consisting of approximately 45 percent of acetone

and 55 percent of naphtha by volume. In the extraction vessel or reactivating filter feed tank, we use 0.3 gallon of 100-percent equivalent acetone, or about 0.67 gallon of the 45-percent acetone-naphtha concentrate per pound of used clay.

### Acetone Losses

The loss of acetone at Wellsville has been somewhat higher than we expected, but this is not surprising when it is considered that much of the equipment used was not designed for the purpose, but was

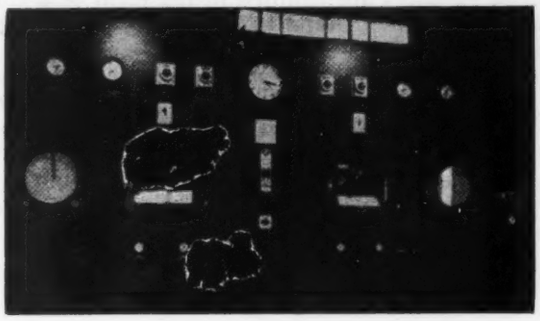

**FIGURE 12**
**Instrument Panel—Contacting System**

adapted to it. We see no reason why the loss of color solvent, for instance acetone, should be very much higher in this type of plant than it is in a solvent-dewaxing plant, if the plant is well designed, and if all of the equipment is of the right type for the various operations involved.

### Maintenance Expense

The decolorizing clay we used is not erosive to the extent of most contact clays. It can be handled by ordinary centrifugal or reciprocating pumps, although the use of open-type impeller centrifugal pumps is thought most desirable in preventing breakdown of the clay particles. Inasmuch as the clay we use is not erosive, the maintenance cost for material and labor on lines, pumps, and all other equipment is very low, averaging $0.0125 per barrel of oil charge.

To date there has been no downtime due to equipment failure, the only lost time on the unit being caused by cleaning the coolers and condensers on the naphtha flash towers. This lost time during the past 5 months has amounted to 126 hours, or 3.4 percent.

The cloth dressing on the rotary filters is 15-ounce chain-weave cotton. The life of this cloth is more than 10 months on the primary deoiling filter, as the present filter cloth has been in continuous service since November, 1940, and is still in good condition. The cloth on the secondary deoiling filter has been in service since February, 1941, and is still in use. On the reactivating filter, a life of the cloth dressing equivalent to that on the deoiling filter is expected, although this has not yet been established.

There has been no replacement of pipe lines, valves, pump parts, mixers, nor other equipment since the process first was put in operation. Therefore, it is impossible to state, and even predict, what the life of the various mechanical parts of the unit will be. It is our opinion, however, that the life of such mechanical parts will be unusually long for this type of application.

### Instrumentation and Controls

All of the instruments used in connection with the process at Wellsville are standard instruments. These are provided for controlling the temperatures, pressures, liquid and slurry levels in containers, and the flow of materials for the various steps of this process. Most of the instruments are arranged on instrument panels. One of these, located on the ground floor in the main pump room, controls the operation of the oil-decolorizing system. The other, located on the upper floor of the filter building, controls the various operating conditions of the clay-reactivating system.

The instrument panel for the oil-decolorizing system is shown in Figure 12. On this panel are located the following instruments:

A Duragage for recording the vacuum on the vacuum tower of the flash system.

Two temperature recorders and an indicating potentiometer for giving temperature control of the heater, the naphtha flash system, the feeds to the various filters, and other critical points in the process.

A flow meter and liquid-level indicator controlling oil feed to the unit and indicating the level in the atmospheric tower.

Controls for firing the oil heaters.

Red and green lights for indicating the high and low levels in the vacuum tower.

Liquid-level indicators for various feed tanks.

Liquid-level alarms (lights) also for the various feed tanks.

The instrument panel for the clay-reactivating system is shown in Figure 13. On this panel are located the following instruments:

Indicating dual-pressure controller for controlling the flue-gas pressure in the hoods of the rotary filters.

Flow meters for controlling the wash naphtha delivered to the sprays of the various rotary filters and for controlling the disposition and flow of the various filtrates. Here are located also liquid-level indicators and liquid-level alarms (lights) used in connection with the various filter feed tanks.

Level alarms (lights) also are provided for indicating the high and low level in the two gas holders.

Of interest on this parallel are glass tubes, one for each blotter press, showing the quality of finished oil being produced.

Additional instruments, of course, are provided as needed, and conveniently are located throughout the various units of the process.

A laboratory test is made in connection with each oil charging stock to determine how much new clay

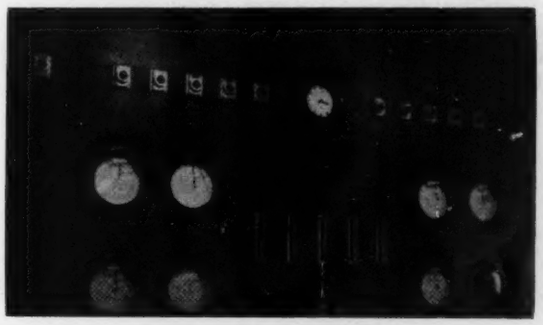

**FIGURE 13**
**Instrument Panel—Reactivating System**

is required to decolorize it to specification color. Actually, reactivated clay is used in the decolorizing step of the process. Its efficiency is assumed to be 85 percent. When any given oil stock is started through the process, sufficient reactivated clay to meet the new clay-decolorizing requirement is used. In order

to meet this indicated amount of reactivated clay in the heater feed tank, a sample of the slurry is tested for its percentage content of solids by weight. The pump transferring this slurry then is set at such a speed that it will deliver the quantity of solids necessary for decolorizing the oil. Usually an excess of solids will be used until a sample of the finished oil can be obtained for color inspection. If the color of the oil from the finished-oil filter is too good, the rate of raw-oil charge is increased, holding the slurry rate constant. The raw oil is measured into the heater feed tank through an ordinary displacement meter, and its feed rate is varied rather than changing the slurry feed rate, because in this manner the rotary filters operate under more constant conditions.

The feed mixture to the rotary filters is controlled by the amount of naphtha or solvent metered into the filter feed tanks.

During the run of each grade of stock a composite sample is collected from all of the control points, and these samples are analyzed for components as a record covering the operation.

We have found our present oil-decolorizing and clay-reactivating process to be quite economical. When everything is taken into consideration, the cost (per barrel of oil decolorized) of applying the process commercially is less than 50 percent of that of the oil-decolorizing process we previously used at Wellsville, and which this process replaced. We believe that the decolorizing cost by this process will compare very favorably with other clay decolorizing processes with which we are familiar.

The process described in this paper is available to anyone interested in it. Licensing arrangements may be made through the Texaco Development Corporation.


## Résumé

The clay treatment of all lubricating-oil stocks at Wellsville is done by a coordinated series of continuous operations whereby the oils are decolorized and the clay reactivated to high efficiency for reuse by extraction with solvents. This process, as now carried out, has been in successful commercial operation at Wellsville since June, 1940, resulting in substantial savings in clay-treating costs.

The oil is contacted with Magnesol, in the presence of some naphtha and traces of acetone, at temperatures just high enough to utilize the clay efficiently and to insure removal of the naphtha and acetone, but not high enough to modify the nature of the coloring matter adsorbed in the clay so that its reactivation becomes difficult or impossible.

We use Magnesol because of its efficiency with our oils at moderately low temperatures, and because it can be reactivated to high efficiency with simple solvents after such use.

Although oils are contacted in naphtha dilution, the process yields oils meeting flash, color, and viscosity specifications without further processing.

Except when first introduced into the system, clay never is handled as a dry powder. Both new and reactivated clays are handled in the form of a slurry or cake with oil or naphtha, in the various steps of this process. When it is finally discarded from the system, the clay contains enough moisture to avoid a dusty condition, which would exist if it were dry.

The complete process (contacting and clay recovery) is a closed system; therefore, no air, moisture, nor other disturbing influence interferes with obtaining best results. This favors low naphtha and color-solvent (acetone) losses.

Our process is free from incidental oxidation and danger of explosion or fire, because we supply a flue-gas atmosphere during certain operations and in certain pieces of equipment.

The process is flexible, handling oils varying from 150 neutral to heavy cylinder stocks. The change-over from one stock to another is simple.

The process has special advantages, which may be listed as follows:

1. The continuous-contacting and clay-reactivating steps are simple in operation, and result in low operating and maintenance costs along with minimum labor requirements.

2. The working conditions of employes is favorable, due to working with slurries, instead of clay powder.

3. A high yield of decolorized oil is realized per unit of new clay used.

4. Heat and steam requirements are much lower than for other contact processes with which we are familiar.

5. Our method of applying the color solvent to the deoiled clay insures complete removal of coloring matter with minimum quantity of color solvent.

6. The process is capable of installation in a relatively small area, and accommodates large throughputs.

7. The relative simplicity with which it is possible to change from one charging stock to another in this type of process.

# Precise Commercial Fractionation in 1000-Barrel Stedman Unit

L. B. BRAGG, Foster Wheeler Corporation
and
F. MORTON, Trinidad Leaseholds, Ltd.

**THE paper describes the design and operation of a commercial fractionation unit (1000 barrels per day) utilizing Stedman packing. The tower is packed with Stedman packing [6-inch triangular sections; *cf.* Bragg, *Trans. Am. Inst. Chem. Engrs.* 37, 19-50 (1941)] having a cross-sectional area of 78:5 square feet and a packed height of 7 feet.**

**Full details of the design are given, with flow sheet and photographs. Three different types of operation are described:**

**A. Fractionation of a straight-run gasoline into seven narrow-boiling fractions, a composite slop fraction, and a still residue. Two of these fractions which contain, respectively, substantially pure *n*hexane and *n*heptane and the residue may be isomerized, cyclized, or reformed. The other fractions, containing substantially all the *iso*paraffins, naphthenes, and aromatics, and the *n*pentane may be variously reblended to give high-octane-rating complementary spirits suitable for blending with *iso*-octane or alkylates to give 100+ aviation fuels.**

**B. Fractionation of special fractions—the example given being the production of a concentrate of isomeric hexanes from a low-octane-rating gasoline, the fraction so obtained having a leaded octane rating of greater than 100.**

**C. Fractionation of a narrow-boiling sidestream from conventional topping unit (boiling range, 210° to 250° F.) to give substantially pure toluene.**

**Brief mention is made of the efficiency, holdup, friction loss, etc., of the packing—full details of which will be published at a later date. The boiling ranges and properties of tank samples are included.**

**The paper is presented under the joint sponsorship of the Foster Wheeler Corporation, New York, N. Y., and Trinidad Leaseholds Ltd., Pointe-a-Pierre, Trinidad, B.W.I., the unit having been erected and tested at the latter's refinery in Trinidad.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, San Francisco, California, November 6, 1941.**

IN LINE with the trend of the industry toward closer and more exact fractionation, a distillation unit was desired that would be capable of producing a number of cuts from light petroleum distillates, each of relatively close boiling range and each quite well fractionated from its neighboring cuts. Following conventional practice, consideration was given first to the design of a continuous-distillation battery containing a number of bubble-tray towers.

The degree of fractionation specified, the number of cuts required, and the close boiling ranges called for made satisfactory control of a continuous battery doubtful. Temperature control seemed out of the question. In view of the number of cuts required, the fact that some of them amounted to only 5 or 6 percent by volume of the feed stock, and as all cuts were to be fractionated closely, it appeared that rate-of-flow control would not be satisfactory, particularly as the composition of feed stock probably would vary.

Consideration, therefore, was given to the possibility of using batch distillation, which offered a better control and one that was independent of feed composition. Batch distillation also presented the possibility of using a low reflux ratio at the start of the taking of any cut and of increasing the reflux ratio as the distillation progressed, until the maximum reflux ratio was reached—near the end of the production of that cut. This permitted a considerable reduction in the average reflux ratio as compared to continuous distillation, which requires the use of maximum reflux ratio at all times. Such a reduction in the average reflux ratio effected corresponding reductions in the quantities of utilities used, in the diameter of the tower, and in the amount of heating and condenser surfaces required. The use of batch distillation also allowed wide variation in the boiling ranges and percentage yields of the several cuts and, with minimum changes, would permit a considerable increase in the number of cuts produced.

When using batch distillation, it is necessary that the "holdup" of the column and of all other parts of the unit handling distillate be reduced to the minimum. This is most important when exact fractionation is required and when some of the cuts represent a small percentage of the charge. As a consequence of this requirement, a bubble-tray column could not be used on account of the considerable liquid holdup of each tray. With the bubble-tray column eliminated, it was natural to turn to a packed column. This was followed by the decision to use Stedman packing, conical and triangular pyramid types of which have been described previously by Stedman[5, 6, 7, 8] and by Bragg,[1, 2, 3, 4] because this packing has a lower holdup than other packing of equivalent capacity and plate efficiency.

## Description of Unit

The unit was designed to operate on a charge of debutanized light gasoline having an ASTM final boiling point of 248° F., and to separate this material into 7 overhead fractions and a still residue. The odd-numbered fractions were to contain substantially all the *iso*paraffins, naphthenes, and aromatics; whereas the even-numbered fractions and the residue were to contain substantially all the normal paraffins. The unit was to process 1,000 barrels of the charging

stock per day. A diagrammatic flow chart of the installation is shown in Figure 1.

The unit consisted primarily of:

1. A still 15 feet in diameter by 40 feet long, arranged to be heated by internal steam coils, and capable of holding a working charge of 1000 barrels of feed stock.

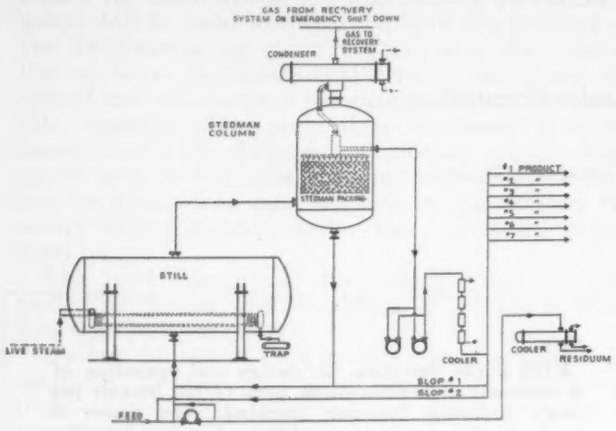


**FIGURE 1**
**Flow Sheet—Stedman Packing Distillation Unit**

2. A Stedman packed column consisting of a cylindrical steel outer sheel 12 feet, 3 inches in diameter by 16 feet long, in which was fitted a cast-steel hexagonal packing casing. The packing casing

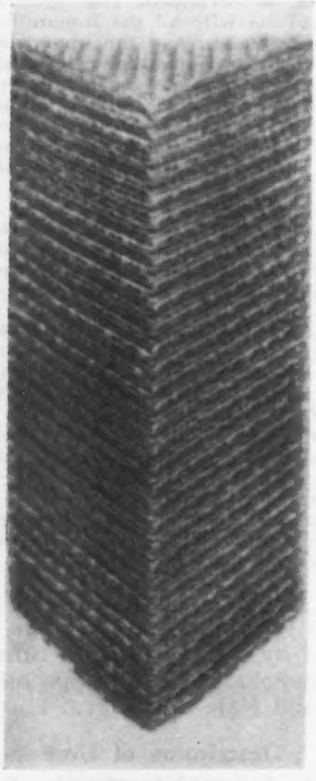

**FIGURE 2**
**Construction of Stedman Packing**

was 5 feet, 6 inches across the faces, 11 feet across the diagonals, and the packed section was 7 feet high.

The casing was packed in layers, each having 726 prism-shaped sections of 6-inch equi-lateral-triangular pyramid-type Stedman packing. The construction of the packing may be visualized by reference to

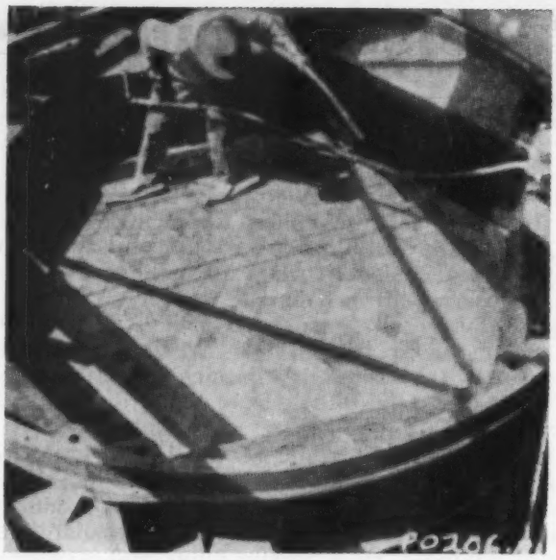

**FIGURE 3**
**Stedman Packing—Casing Partly Packed**

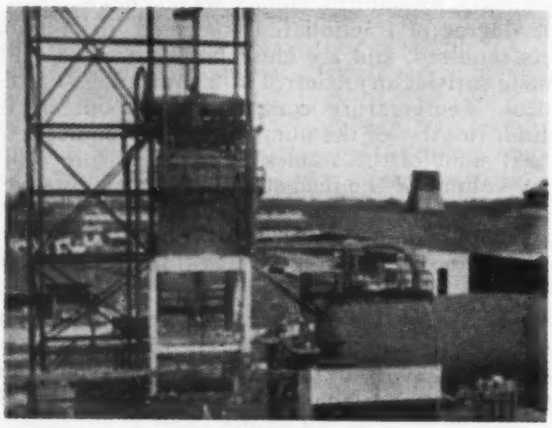

**FIGURE 4**
**Stedman Packing Unit**

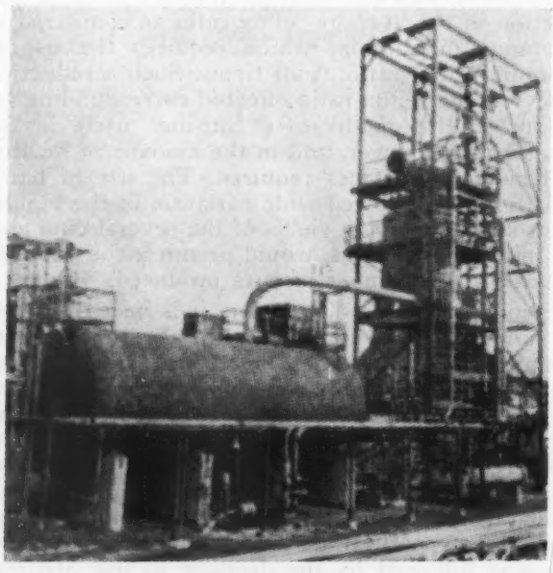

**FIGURE 5**
**Stedman Packing Unit**

Figure 2, which is a photograph of a single section, 1 foot long, and by reference to previous papers on Stedman packing.[3, 4] There were 8 layers; 6 were 1 foot in height, one was 10 inches in height; and one, the top layer, was 2 inches in height. The 2-inch sections were used to provide a layer that could be removed easily and cleaned of scale and dirt that might collect. No such cleaning has been found necessary during approximately 16 months' operation.

The outer portion of the casing was circular in cross-section, and was arranged so that packing material could be driven into a packing gland between the casing and the tower shell to make a tight joint at the top of the casing. The space between the casing and the shell was open at the bottom so that vapors from the still could enter this space and provide a vapor jacket, thereby substantially eliminating heat losses from the packed section. Figure 3 is a photograph taken looking down into the casing when it was partly packed.

3. A conventional, horizontal, overhead condenser arranged for vapor admission at the bottom center of the shell, and for removal of product and reflux condensate from the bottom of the shell on each side of the vapor inlet. A vent connection was made to the top of the condenser shell.

4. A reflux distributor consisting of a spider manifold to which were connected 726 tubes, 3/16-inch OD, 1/8-inch ID, each about 7 inches long, one for each section in the top layer of packing. These tubes directed the streams of reflux to the approximate center of each triangular-shaped section of packing and, by offering equal flow resistances, provided substantially equal division of the reflux liquid between the 726 columns of packing.

5. Necessary product and residue coolers, product pumps, a combination feed and still-residue pump, suitable control instruments, valves, piping, and product tanks. The unit is shown in Figure 4, which is a view of the still, column, instrument shelter, product pumps, product cooler, product valve manifold, and — through the steel work — the residue cooler. Figure 5 is a view from the opposite side.

The packing as used in this tower has a fractionating ability corresponding to about 4 theoretical plates per foot of height, or 28 theoretical plates for the 7 feet of packing. The liquid and vapor holdup of the column under operating conditions amounted to approximately 25 barrels. The friction loss through the column was about 0.5 in. of mercury.

## Operation of Unit

Three different types of operation of the unit are reported herein. All three call for the same handling of the controls, however, and all three will be described simultaneously.

In all cases the still first was charged with 1,000 barrels of feed stock by means of the feed pump and connecting pipe lines. When the charge was in the still, steam was admitted to the heating coils at the desired predetermined rate.

After the temperature within the still had reached the boiling point, vapors rose through the vapor line into the base of the column and up through the Stedman packing into the condenser. Here they were condensed and returned as liquid to a collector below the condenser, from which the desired portion was removed as product and the balance returned to the column as reflux. The reflux entered the packing through the reflux-distributing spider, flowed down through the packing into the base of the column, and through the reflux return line into the still.

At the start of a run, if non-condensables were present, the pressure within the unit would rise until a pressure-control valve in the vent line opened and allowed gases to vent from the unit. As soon as the non-condensables were vented sufficiently from the condenser, the control valve closed and the pressure then gradually dropped as the distillation progressed, until the pressure in the top of the condenser became equal to that of the atmosphere. A valve then was opened, allowing air to enter as necessary, to blanket a portion of the condensing surface and to hold the pressure in the top of the condenser constant for the balance of the run.

At the start of a run a slop valve was opened for a short time to clear the product lines of material remaining from the previous run. The material so slopped returned to the still.

The product rate was regulated as desired by a flow controller, which also provided predetermined reflux ratios in the tower — these reflux ratios being altered in steps when predetermined vapor temperatures were attained in the vapor line leaving the tower.

At predetermined top tower temperatures, the product valve being used was first held open for a period of time sufficient to allow the piping from the top of the tower to the pump and the valve to be purged, and the product valve was then closed. Following the closing of the product valve, a second slop valve was opened for a period of time sufficient to clear the tower, pump, and piping of the improperly fractionated material that results from the holdup of the tower. The material slopped through the valve was pumped to the bottoms tank. At the end of the slop period the slop valve was closed, and the valve to the next product rundown tank was opened.

The runs continued in this fashion until the last overhead cut had been produced and the column holdup slopped. The steam was then shut off, and the residue pumped from the still through the residue cooler to the residues rundown tank.

### Operation "A" — Making a Series of Cuts

In operation "A" the unit was charged with a light distillate fraction, and the unit operated at 3 reflux ratios of 7:1, 15:1, and 30:1, respectively — removing approximately 80 percent of each cut at a reflux ratio of 7:1; then approximately 10 percent at a reflux ratio of 15:1 and, finally, approximately 10 percent at a reflux of 30:1. Thus the average reflux ratio was approximately 10:1. Seven distillate cuts, one combined slop cut, and a residue cut were produced. The characteristics of the charge, tank samples, and blended tank samples are shown in Table 1.

"True-boiling-point" distillations of the feed and tank samples were made also using a 25-mm-diameter No. 112 conical-type Stedman packed column with 1 foot of packed section. These data are presented graphically in Figure 6.

### Operation "B" — Isomeric-Hexane Concentrate

In operation "B" the unit was charged with a rerun-tower sidestream. With this charging stock, the unit was operated at a constant reflux ratio of 15:1, using only 4 feet 10 inches of Stedman packing, equivalent to about 19 theoretical plates. Two distillate cuts and a residue were produced. In order to pro-

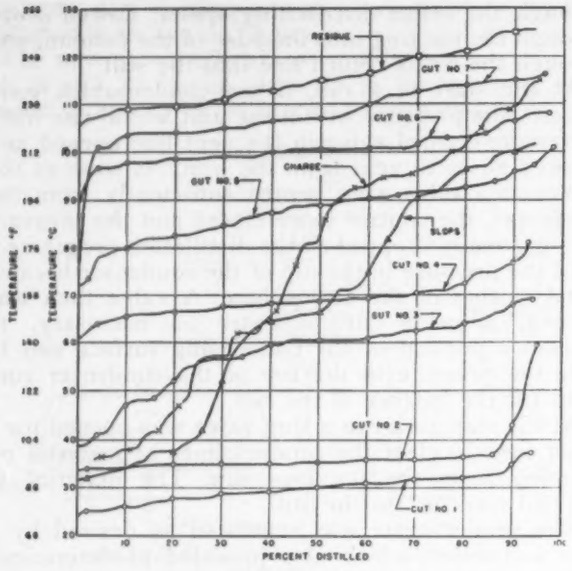


**FIGURE 6**
**True-Boiling-Point Distillation, Operation "A"**

vide material for additional experimental work, a third overhead cut was taken. Details of this fraction are included herein for record purposes. The characteristics of the charging stock and products are shown in Table 2. "True-boiling-point" distillations of the charge, distillate, and residue samples are presented graphically in Figure 7.

### Operation "C" — Toluene Concentrate

In this operation the unit was charged with a rerun-tower sidestream. The unit was operated first to produce two distillates and a residue. The first distillate contained material distilled up to a point where the distillate stream had approximately the same toluene content as the original charge. The second distillate contained material distilled up to the point

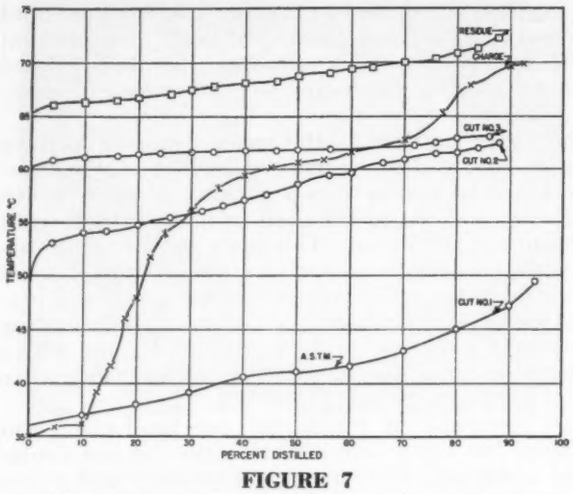


**FIGURE 7**
**True-Boiling-Point Distillation, Operation "B"**

where the distillate stream had fallen again to approximatey the toluene content of the charge.

The unit was next operated using the second distillate from the preliminary concentration as a charging stock. The unit was operated again to produce two distillates and a residue, in the same manner as during the preliminary concentration.

The characteristics of the charging stock and of the several products are shown in Table 3. "True-boiling-point" distillations of the charge and products are shown in Figure 8.

**TABLE 1**
**Operation "A"**

| SAMPLE | Yield (Percent by Volume) | Reid Vapor Pressure (Pounds) | Gravity (°API) | ASTM DISTILLATION, IN °F | | | | | CFR-ASTM Octane No. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Initial Boiling Point | 10 Percent Point | 50 Percent Point | 90 Percent Point | End Point | Clear | Plus 3.3 Ml TEL* Per Per Gallon |
| Charge | 100.00 | 5.9 | 64.4 | 117 | 151 | 189 | 232 | 268 | 68.8 | 86.4 |
| Tank—cut 1 | 5.6 | .... | 94.7 | ... | ... | ... | ... | ... | 85.0† | 100.0† |
| Tank—cut 2 | 6.7 | .... | 91.4 | 91 | 97 | 99 | 109 | 183 | 69.9 | 89.1 |
| Tank—cut 3 | 7.0 | .... | 76.9 | 126 | 132 | 136 | 145 | 174 | 77.0 | 95.0 |
| Tank—cut 4 | 18.4 | .... | 67.0 | 151 | 156 | 158 | 162 | 185 | 65.7 | 85.5 |
| Tank—cut 5 | 18.5 | .... | 60.5 | 178 | 187 | 189 | 198 | 219 | 71.2 | 88.1 |
| Tank—cut 6 | 18.8 | .... | 54.7 | 205 | 210 | 213 | 217 | 239 | 63.4 | 82.5 |
| Tank—cut 7 | 3.2 | .... | 53.1 | 217 | 226 | 232 | 238 | 262 | 69.2 | 85.8 |
| Tank—slops | 6.8 | .... | 70.7 | 115 | 133 | 158 | 206 | 234 | 72.4 | 90.0 |
| Residue | 12.2 | .... | 52.6 | 252 | 256 | 261 | 270 | 293 | 56.4 | 74.7 |
| Butane and loss | 2.8 | .... | .... | ... | ... | ... | ... | ... | .... | .... |
| Blend cuts, 1, 3, 5, 7 | 34.3 | 6.9 | 68.0 | 120 | 144 | 174 | 203 | 237 | 74.3 | 90.9 |
| Blend cut 2 and slops | 13.5 | 12.5 | 79.3 | 99 | 111 | 124 | 188 | 230 | 71.7 | 90.9 |
| Blend cuts 4, 6 and residue | 49.4 | 2.9 | 57.7 | 167 | 185 | 205 | 246 | 277 | 62.0 | 81.0 |
| Blend cuts 1, 3 | 12.6 | 14.0 | 84.7 | 95 | 104 | 118 | 140 | 165 | 79.2 | 97.3 |
| Blend cuts 2, 5, 7 and slops | 35.2 | 6.1 | 66.3 | 120 | 149 | 180 | 207 | 237 | 71.0 | 88.8 |
| Blend cuts 1, 2, 3, 5, 7 and slops | 47.8 | 8.0 | 70.8 | 113 | 131 | 163 | 202 | 244 | 73.4 | 91.0 |

* Tetraethyl lead. † Blending value.

**TABLE 2**
**Operation "B"**

| SAMPLE | Yield (Percent by Volume) | Gravity (°API) | ASTM DISTILLATION, IN °F | | | | | CFR-ASTM Octane No. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Initial Boiling Point | 10 Percent Point | 50 Percent Point | 90 Percent Point | End Point | Clear | Plus 3.3 Ml TEL Per Gallon |
| Charge | 100.0 | 79.2 | 122 | 129 | 136 | 145 | 183 | 73.3 | .... |
| Tank—cut 1 | 18.2 | 89.0 | 97 | 99 | 106 | 117 | 151 | 71.5 | .... |
| Tank—cut 2 | 31.7 | 77.3 | 126 | 131 | 134 | 138 | 147 | 83.8 | 100.7 |
| Tank—cut 3 | 31.4 | 80.8 | 138 | 140 | 142 | 143 | 167 | 75.0 | 94.9 |
| Residue | 13.8 | 71.4 | 140 | 153 | 154 | 158 | 210 | 61.2 | .... |
| Butane and loss | 4.9 | .... | ... | ... | ... | ... | ... | .... | .... |

**TABLE 3**
**Operation "C"**

| SAMPLE | Yield (Percent by Volume | Gravity (°API) | ASTM DISTILLATION, IN °F | | | | | Toluene Content (Percent by Volume) |
|---|---|---|---|---|---|---|---|---|
| | | | Initial Boiling Point | 10 Percent Point | 50 Percent Point | 90 Percent Point | End Point | |
| FIRST RUNNING | | | | | | | | |
| Charge | 100.0 | 53.7 | 212 | 221 | 228 | 239 | 273 | 14.1 |
| Tank—cut 1 | 14.6 | 58.4 | 201 | 205 | 208 | 214 | 239 | 6.9 |
| Tank—cut 2 | 66.6 | 52.5 | 212 | 219 | 224 | 231 | 259 | 19.5 |
| Residue | 16.5 | 54.0 | 248 | 252 | 255 | 262 | 304 | 1.0 |
| Loss | 2.3 | .... | ... | ... | ... | ... | ... | .... |
| RERUNNING TANK—CUT 2. | | | | | | | | |
| Tank—cut 1A | 37.0 | 54.1 | 203 | 208 | 212 | 216 | 234 | 15.2 |
| Tank—cut 2A | 39.2 | 48.5 | 219 | 221 | 223 | 226 | 250 | 34.0 |
| Residue A | 22.7 | 57.4 | 239 | 244 | 247 | 250 | 275 | 1.0 |
| Loss | 1.1 | .... | ... | ... | ... | ... | ... | .... |


## Summary

The operations described indicate the commercial feasibility of large-diameter columns packed with Stedman packing, and show that narrow-boiling fractions can be obtained with a high degree of separation. For specific fractions, such as the production of substantially pure hydrocarbons, it will be necessary to use a greater packed height than has been used in the operations under discussion.

As has been indicated in the foregoing discussion, the batch Stedman unit offers the possibility of making a large number of cuts from a single charging stock, with good control and exact fractionation, even with varying feed composition. The present state of the art of controlling continuous bubble-tray batteries does not permit satisfactory operation to meet such requirements. In addition, batch operation permits one to take advantage of the possibility of using reduced reflux ratios in the early stages of the run, thereby reducing utility consumption and the size of the tower, condenser, and heating coils. Batch operation permits wide flexibility in the operation of the unit such as may be required to meet changing market demands.

Stedman packing is also particularly suitable for use: *a*, in continuous-distillation units, with charging stock of substantially constant composition; *b*, when a large number of theoretical plates is required; *c*, when a low friction loss per theoretical plate is necessary; and, *d*, when moderate to high efficiency columns of small diameter are desired.



## Acknowledgment

The authors wish to acknowledge the services of A. R. Richards, R. A. Findlay, W. J. Loveless, and P. M. Greer who conducted most of the tests and who assisted in the work.


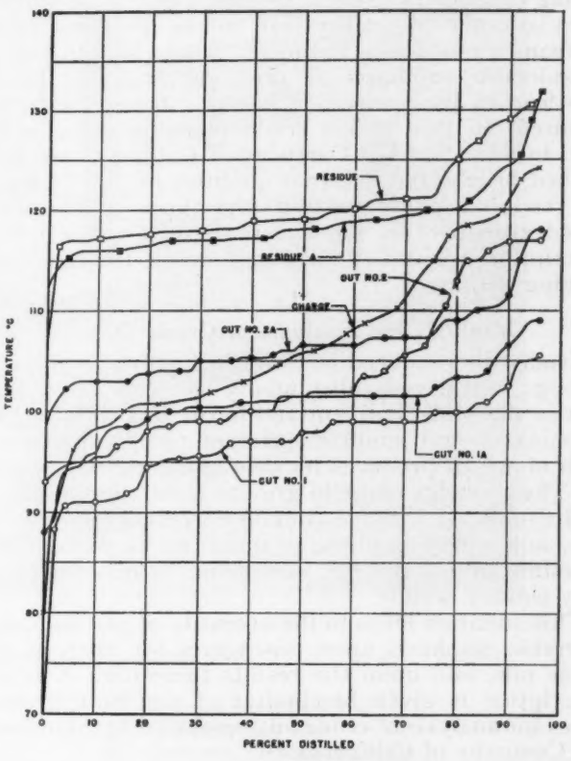


**FIGURE 8**
**True-Boiling-Point Distillation, Operation "C"**


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# Characteristics of California Crude Oils

R. C. MITHOFF, G. R. McPHERSON and F. SIPOS
Standard Oil Company of California

**BRIEF description is given herein of the crude-oil analysis methods employed by Standard Oil Company of California. Based upon results of these analytical methods, California crude oils are compared with oils produced elsewhere in the United States. It is shown that the California crude oils are heavier, more viscous, substantially more naphthenic, of higher sulphur content, and of different boiling characteristics than are most Mid-Continent, Pennsylvania, and Texas crude oils. They also produce gasoline of substantially higher octane number. Description is given of the ways in which the refining requirements of California oils differ from those of eastern oils.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 5, 1941.**

CALIFORNIA crude oils differ markedly from most other crude oils produced in the rest of the United States in gravity, paraffinicity, sulphur content, and asphalt content. They also differ markedly among themselves in these factors. These wide variations in crude-oil quality lead to the necessity that companies processing California stocks should place considerable emphasis on crude-oil analysis. They also lead to wide variation in the refining methods required. In this paper, crude-oil-analysis methods used by Standard Oil Company of California are described briefly, the different qualities of the California crude oils are compared with those of oils produced elsewhere in the United States, and a brief description is given of the differences in the required refining processes.

### Methods for Analysis of Crude Oils

Crude oils produced in California differ in quality among themselves substantially more than is the case in the Mid-Continent and in the East. The state contains several hundred different pools and zones, each of which produces its own characteristic crude oil. These crudes range in gravity from approximately 6 to 60° API. Some contain essentially no gasoline, and others contain as much as 85 percent of gasoline with a 390° F end point. Other qualities vary equally widely.

This situation leads to the necessity of placing considerable emphasis upon procedures for analysis of crude oils, and upon the results therefrom. A brief description is given hereinafter of the main procedures for analysis of crude oils employed by Standard Oil Company of California.

### Crude Analysis Methods "A," "B," and "D"

The equipment developed and used by Standard Oil Company of California for making analyses by the methods designated "A," "B," and "D" is shown in Figure 1. It consists of a 5-liter stainless-steel flask equipped with a 29-inch glass column made from 45-mm pyrex-glass tubing. The column is filled to a depth of 18 inches with 4-mm x 6-mm glass nipples, and is fitted at the top with an internal reflux condenser. The column is protected against heat loss by a readily removable, 85-percent magnesia insulating jacket. The distillate is condensed in an ice-cooled stainless-steel condenser, and collected in an ice-cooled, stoppered, 2,000-ml graduated cylinder. A vapor-recovery system is connected to the vent from the receiver. It consists of a calcium-chloride drier and after-condensers cooled with a slurry of solid carbon dioxide and chloroform.

The method of heating the flask is an important feature. A cast-iron star burner of the usual type used in hot plates is employed, except that the venturi section is replaced by tight connections to the gas and compressed-air supplies. The gas is discharged into the mixing section through the usual jet. This arrangement permits accurate and reproducible control of the height and temperature of the flame.

Safety features include use of a wire-inserted clear-glass safety shield in front of the still, a metal flask, a sand-filled catch pan below the flask, and a mercury-bubbler pressure relief on the line to the after-condenser.

About 4,000 ml of crude oil is charged to the still by means of a siphon through the steam connection on the flask. It then is warmed gently for about 15 minutes or until the crude is dehydrated, and foaming and bumping have ceased. The flame then is regulated to produce net overhead at the rate of about 0.2 percent of the volume of charge per minute. When the vapor line reaches 225° F, the insulation is put onto the column, and air admitted to the reflux condenser. The flame and air are regulated so that the distillation rate is maintained, and so that the column operates just slightly below the flooding stage.

A first cut, somewhat lighter than the lightest gasoline to be made, is collected and stored, with provision to prevent loss of light end. One-percent cuts then are collected in open graduated cylinders, until the end of the distillation. Superheated steam is introduced as a distillation aid when the still temperature reaches 550 to 625° F.

With heavy or wet crude oils it is sometimes necessary first to distill the crude oil in a larger metal still, without fractionation, to produce a wide blanket overhead cut, which later is redistilled in the previously described equipment.

The operating procedures for methods "A," "B," and "D" differ only in the depth to which the crude

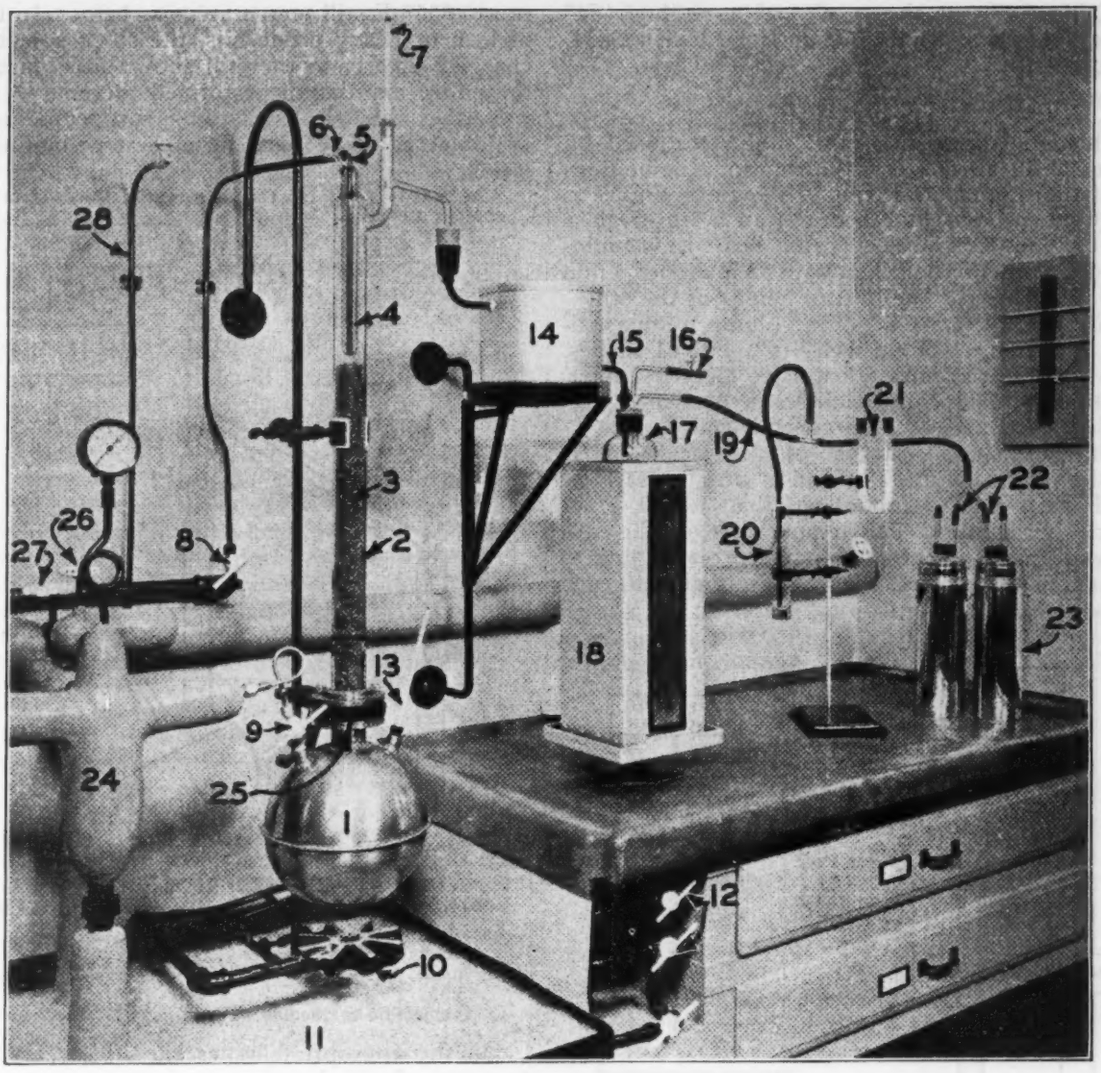


**FIGURE 1**
**Distillation apparatus for crude analysis—5-liter still.**

1. Distillation flask (5,000-ml)
2. 29-inch fractionating column
3. Column packing
4. Reflux condenser
5. Inlet air to reflux condenser
6. Air outlet to atmosphere
7. ASTM thermometer, 30 to 580° F
8. Air-control valve
9. Steam-control valve to still
10. Burner, air-gas-mixture blow-type
11. Sand-filled safety catch pan
12. Controls for gas and air valves
13. ASTM thermometer, 30 to 760° F
14. Condenser
15. Overhead rundown line
16. Gas-absorbing line
17. Receiver, 2,000-ml capacity
18. Receiver holder (ice and water bath)
19. Gas vent line
20. Safety pressure release
21. Calcium-chloride drier
22. After-condensers
23. Holders for after-condensers
24. Steam superheater
25. Flange support
26. Low-pressure steam valve
27. High-pressure steam valve
28. Water line for reflux condenser

oil is distilled. The stock is run so that the different cuts can be blended proportionally to produce the following stocks:

*Method "A"*

Gasoline of 390° F end point.
Residuum following 390°-F-end-point gasoline.

*Method "B"*

Gasoline of 390° F end point.
Kerosine distillate (400 Saybolt-Thermo viscosity) following 390°-F-end-point gasoline.
Residuum following the foregoing kerosine.

*Method "D"*

Three gasolines: end point, respectively, 340, 390, and 437° F.
Kerosine distillate (360 Saybolt-Thermo viscosity) following 340°-F-end-point gasoline.
Kerosine distillate (400 Saybolt-Thermo viscosity) following 390°-F-end-point gasoline.
Gas oil (viscosity, 40 sec Saybolt Universal, at 100° F) following 390°-F-end-point gasoline.
Residuum following 390°-F-end-point gasoline.
Residuum following 400-viscosity kerosine.
Residuum following 40-viscosity gas oil.

Appropriate inspections of each stock are obtained. The results are recorded in tabular form on a single sheet of paper, one crude oil to each sheet. These sheets are bound in loose-leaf books, which are revised and kept up to date as new data become avail-

able. Table 1 shows the results of a method "D" analysis of a typical crude oil from Long Beach Field, California.

### True-Boiling-Point Analysis

A schematic diagram of the equipment used by Standard Oil Company of California for true-boiling-point distillation of crude oils is shown in Figure 2. The equipment consists essentially of a 2-liter glass flask attached to an electrically heated, vacuum-jacketed glass column packed with 32 inches of 8-mm glass Raschig rings. The overall height of the still—including flask, expansion joint, column, reflux condenser, and thermocouple well—is about 61 inches. The flask is heated with a bag-type electric heater. The auxiliary equipment includes a condenser, receiving system, and vacuum control equipment.

A chilled 1,500-ml sample of the crude oil is charged to the flask and distilled at a reflux ratio of approximately 8 to 1—producing about 1.5 ml of net overhead per minute. The temperature of the still and vapor line is recorded at times corresponding to each 2 percent overhead. Cuts corresponding to each

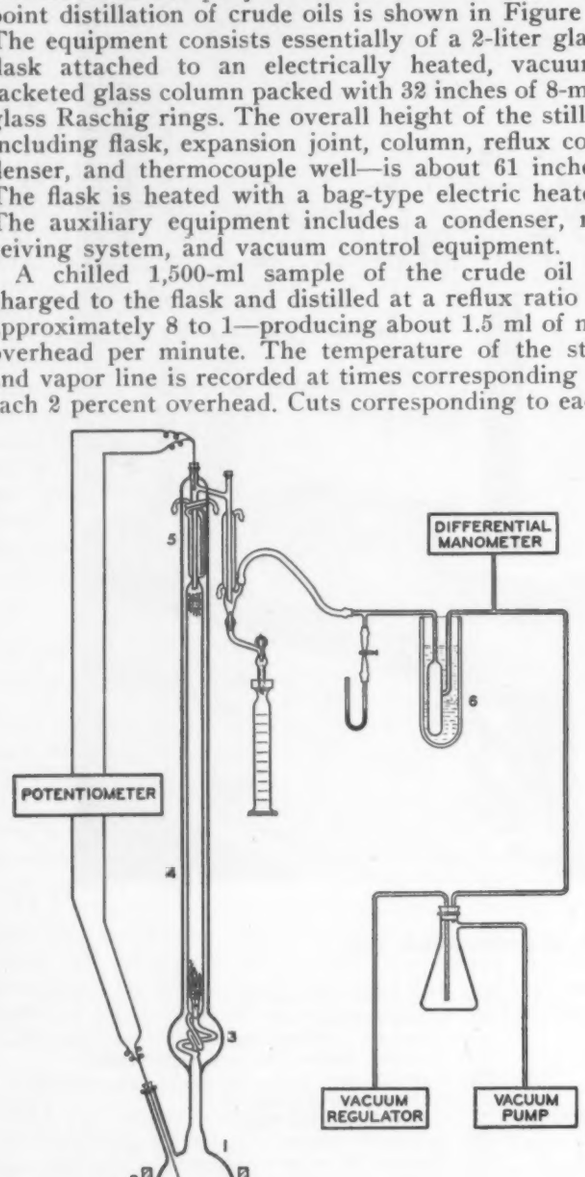


**FIGURE 2**
**Apparatus for true-boiling distillation.**

1. 2-liter flask
2. Bag-type electric heater
3. Thermal-expansion joint
4. Electrically heated, vacuum-jacketed column, 28-mm ID
5. Internal reflux condenser
6. Carbon-dioxide-chloroform after-condenser

4 percent from still charge are collected separately.

The distillation is performed at atmospheric pressure, until the still temperature reaches 635° F. The still then is cooled, evacuated to 10-mm pressure, and again run to 635° F still temperature. The still is cooled, and the contents transferred to the still (shown in Figure 3) which has a shorter column. This still is evacuated to about 1-mm pressure, and run to 635° F still temperature as before. In the case of lean or heavy crude oils, the stock sometimes is charged directly to the still shown in Figure 3, and the entire distillation performed therein.

Neither ASTM distillations nor octane numbers are obtained on the cuts from the true-boiling distillation.

The data from the true-boiling distillation are of

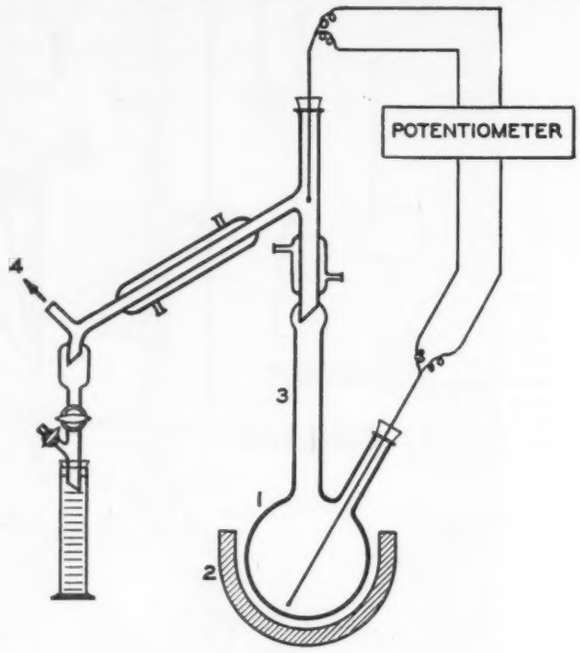


**FIGURE 3**
**Modified true-boiling apparatus for heavy residuum.**

1. 2-liter flask
2. Bag-type electric heater
3. Insulated open column (Vigreaux type), 28-mm IDx254 mm
4. Connection to vacuum system

On the appropriate 4-percent cuts, the following tests are obtained:

1. Gravity.
2. Kinematic viscosity at two or three temperatures.
3. Sulphur.
4. Neutralization number.
5. Pour point.
6. Aniline point.
7. Molecular weight (from gravity and boiling point).

considerable value when used in conjunction with results of method "D" analysis to estimate the yield and quality of distillates other than those shown in the "D" method. It is, therefore, the practice in Standard Oil Company of California to correlate the results of true-boiling distillations and method "D" analyses on each crude oil on which both sets of data are obtained, and to prepare a separate report and set of charts for each of such crude oils.

Table 2 shows the results of a true-boiling-point distillation of a typical crude oil from the Long Beach field, California.

### Characterization Gravity

The characterization gravity is a test developed several years ago by Standard Oil Company of California to measure the paraffinicity of heavy oils. It serves essentially the same purpose as does the UOP characterization factor "K," [1] except that it is susceptible of more accurate measurement. The characterization gravity also affords a somewhat more accurate means of estimating the octane number of

gasoline made by cracking heavy residuums than does the UOP "K."

The characterization gravity is the arithmetic average of the instantaneous gravities of the distillate boiling at 350, 450, and 550° F vapor-line temperature at 25-mm pressure in a true-boiling-point distillation. It may be calculated from any true-boiling-point distillation by means of a Cox chart, provided the true-boiling-point distillation is carried far enough. It often is determined also on heavy residuums by the performing of a special true-boiling-point distillation at 25-mm pressure in the still shown in Figure 3.

The characterization gravity is determined on essentially all unfamiliar crude oils analyzed by Standard Oil Company of California, and is used primarily to classify the stock as to its paraffinicity.

### Heart-Cut Analysis

The heart-cut analysis is made on crude oils for which highly detailed analytical data are desired. About 15 gallons of the crude oil is run with good fractionation in a 20-gallon metal still equipped with an efficient fractionating column. Steam may be used as a distillation aid, and vacuum may be employed. The crude oil is separated into narrow-boiling cuts, each corresponding to about 5 percent yield from the original crude oil. The narrow cuts are blended proportionally to produce a large number of gasolines, heart cuts, and residuums of different boiling ranges, and detailed inspections are obtained. The first cut usually is rectified before blending.

If the analysis is not to be carried in excess of approximately 700° F, the raw crude oil may be used in the foregoing distillation. If heavier cuts are to be made, it is necessary first to run the original crude oil to pitch without fractionation, producing a blanket overhead cut, which later is rerun with fractionation to produce the narrow cuts.

The resulting data are correlated, and plotted upon charts showing the different qualities as functions of the percent from crude oil at the start and at the end of the desired distillate. Figures 4 and 5 are examples of charts of this type, showing the sulphur and viscosity of heart cuts from a crude oil from the Kettleman Hills field.

Conventional charts showing quality of gasolines and of residuums vs. yield from crude oil are prepared also from the foregoing data. True-boiling-point analysis, fractional analysis, and an equilibrium-flash breakdown usually are obtained also on

**TABLE 1**
**Method "D" analysis of typical crude oil from Long Beach field, California**

| | | GASOLINES | | | | KEROSINE DISTILLATE | | GAS OIL | RESIDUUM AFTER | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 390 °F. End-Point | | | | | | | | |
| | Dry Crude | 340 °F. End-Point | Unrectified | Butane-free | 437 °F. End-Point | 360-Viscosity (Saybolt-Thermo) After 340 °F. End-Point | 400-Viscosity (Saybolt-Thermo) After 390 °F. End-Point | 40-Viscosity (Saybolt Universal) at 100 °F After 390 °F End-Point | 390 °F. End-Point Gasoline | 400-Viscosity Kerosine Distillate | 40-Viscosity Gas Oil |
| Yield: | | | | | | | | | | | |
| Percentage net from crude as received | .... | 15.6 | 20.8 | 20.8* | 25.5 | 14.4 | 7.2 | 31.2 | 79.2 | 72.0 | 48.0 |
| Percentage from butane-free crude | .... | .... | .... | 20.8* | .... | .... | .... | .... | .... | .... | .... |
| Percentage range from crude | .... | 0–15.6 | 0–20.8 | .... | 0–25.5 | 15.6–30.0 | 20.8–28.0 | 20.8–52.0 | 20.8–100.0 | 28.0–100.0 | 52.0–100.0 |
| Butanes and lighter, percent* | 0.0 | .... | 0.0 | .... | .... | .... | .... | .... | .... | .... | .... |
| Gravity, deg. A.P.I. | 25.1 | 57.2 | 53.8 | .... | 51.1 | 40.1 | 38.9 | 32.7 | 19.3 | 17.7 | 11.6 |
| Flash Point: | | | | | | | | | | | |
| Tag. closed cup, °F.* | .... | .... | .... | .... | .... | 135 | 165 | .... | .... | .... | .... |
| Pensky-Martens, °F.* | .... | .... | .... | .... | .... | .... | .... | 213 | .... | .... | .... |
| Cleveland open-cup, °F. | .... | .... | .... | .... | .... | .... | .... | .... | 250 | 300 | 470 |
| Viscosity: | | | | | | | | | | | |
| Saybolt-Thermo | .... | .... | .... | .... | .... | 355 | 395 | .... | .... | .... | .... |
| Saybolt Universal at 35 °F., sec. | 1,030 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Saybolt Universal at 70 °F., sec. | 247 | .... | .... | .... | .... | .... | .... | 45.3 | .... | .... | .... |
| Saybolt Universal at 100 °F., sec. | 121 | .... | .... | .... | .... | .... | .... | 39.0 | 724 | .... | .... |
| Saybolt Universal at 130 °F., sec. | .... | .... | .... | .... | .... | .... | .... | .... | 301 | 541 | .... |
| Saybolt Universal at 210 °F., sec. | .... | .... | .... | .... | .... | .... | .... | .... | 69 | 93 | 777 |
| Pour point, °F. | +15 | .... | .... | .... | .... | .... | .... | +15 | +45 | +50 | +85 |
| Sulphur, percent by weight | 1.16 | 0.040 | 0.058 | .... | 0.088 | 0.22 | 0.245 | 0.78 | 1.40 | 1.48 | 1.73 |
| Wax (Holde), percent | 2.20 | .... | .... | .... | .... | .... | .... | .... | .... | 3.11 | .... |
| Water and sediment, percent | 0.20 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Water by distillation, percent | 0.20 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Reid vapor pressure, lb. | 1.75 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Saponification No. | 0.67 | .... | .... | .... | .... | .... | .... | .... | .... | 0.64 | .... |
| Conradson carbon residue, percent | .... | .... | .... | .... | .... | .... | .... | .... | 7.61 | 8.81 | 11.7 |
| Delay cetane No.* | .... | .... | .... | .... | .... | 39.2 | 41 | 47 | .... | .... | .... |
| Neutralization No., mg of potassium hydroxide per gram | .... | .... | .... | .... | .... | .... | 0.30 | 0.57 | .... | .... | .... |
| Aniline point, °F. | .... | .... | .... | .... | .... | .... | 136 | 146.5 | .... | .... | .... |
| Characterization gravity, deg. A.P.I. | .... | .... | .... | .... | .... | .... | .... | .... | .... | 27.2 | .... |
| Smoke tendency (lamp), mm | .... | .... | .... | .... | .... | 32 | 33 | .... | .... | .... | .... |
| Octane No., CFR motor method | | | | | | | | | | | |
| Clear | .... | 63.5 | 59.9 | .... | 55.0 | .... | .... | .... | .... | .... | .... |
| Plus 1.0 ml TEL † per gal. | .... | .... | 69.0 | .... | .... | .... | .... | .... | .... | .... | .... |
| Plus 2.0 ml TEL † per gal. | .... | .... | 73.5 | .... | .... | .... | .... | .... | .... | .... | .... |
| Natural gasoline to obtain 170 °F. at 20-percent point* | .... | .... | 30.4 | .... | .... | .... | .... | .... | .... | .... | .... |
| Octane No. after natural-gasoline blending* | .... | .... | 64.5 | .... | .... | .... | .... | .... | .... | .... | .... |
| Average boiling point | .... | 243 | 271 | .... | 300 | 413 | 431 | 552 | .... | .... | .... |
| | D-158 | D-86 | D-86 | .... | D-86 | D-86 | D-86 | D-158 | .... | .... | .... |
| ASTM Distillation, in °F.: | | | | | | | | | | | |
| Initial boiling point | 140 | 126 | 133 | .... | 142 | 356 | 398 | 432 | .... | .... | .... |
| 5 percent point | 260 | 173 | 183 | .... | 188 | 367 | 407 | 470 | .... | .... | .... |
| 10 percent point | 300 | 190 | 202 | .... | 210 | 377 | 412 | 478 | .... | .... | .... |
| 20 percent point | 416 | 209 | 226 | .... | 238 | 386 | 418 | 492 | .... | .... | .... |
| 30 percent point | 516 | 223 | 244 | .... | 260 | 394 | 421 | 508 | .... | .... | .... |
| 40 percent point | 599 | 234 | 258 | .... | 271 | 401 | 425 | 526 | .... | .... | .... |
| 50 percent point | .... | 244 | 273 | .... | 299 | 409 | 428 | 545 | .... | .... | .... |
| 60 percent point | .... | 255 | 289 | .... | 319 | 419 | 433 | 571 | .... | .... | .... |
| 70 percent point | .... | 265 | 303 | .... | 342 | 429 | 438 | 591 | .... | .... | .... |
| 80 percent point | .... | 281 | 324 | .... | 372 | 441 | 445 | 612 | .... | .... | .... |
| 90 percent point | .... | 293 | 343 | .... | 399 | 457 | 456 | 644 | .... | .... | .... |
| 95 percent point | .... | 310 | 363 | .... | 422 | 472 | 468 | 658 | .... | .... | .... |
| End point | 625 | 340 | 390 | .... | 437 | 483 | 477 | 680 | .... | .... | .... |
| Recovery, percent | 44.5 | 99.0 | 99.0 | .... | 99.0 | 98.0 | 99.0 | 99.0 | .... | .... | .... |
| Loss, percent | .... | 0.0 | 0.0 | .... | 0.0 | .... | .... | .... | .... | .... | .... |

* Estimated. † Tetraethyl lead.

**TABLE 2**

**True-boiling-point distillation of typical crude oil from Long Beach field, California.**

**Gravity of Crude Oil—25.1 Deg API**

| DISTILLATION DATA | | | | | | INSPECTION OF CUTS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Viscosity | | | | | | | | | | | |
| | | | | | | | Kinematic (Centistokes) | | | Saybolt-Universal (Seconds) | | | | | | | | |
| Vapor Temperature (°F.) | Volume Distilled Based on Crude (Percent) | Pressure (Millimeters of Mercury, Absolute) | Temperature, Converted to 760-Mm Pressure (°F.) | Mid-point (Percent Distilled) | Vapor Temperature at Mid-point Percent Distilled (°F.) | Gravity (° API) | 100 °F. | 130 °F. | 210 °F. | 100 °F. | 130 °F. | 210 °F. | Saybolt-Thermo* | Sulphur (Percent by Weight) | Neutralization No. (Milligrams of Potassium Hydroxide Per Gram of Oil) | Pour Point (°F.) | Aniline Point (°F.) | Molecular Wt. |
| 143 | 2 | | 143 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 166 | 4 | | 166 | 2 | 143 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 190 | 6 | | 190 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 240 | 8 | | 240 | 6 | 190 | 56.6 | 0.65 | 0.56 | 0.42 | .... | .... | .... | .... | 0.010 | .... | .... | .... | 100† |
| 260 | 10 | | 260 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 281 | 12 | | 281 | 10 | 260 | 53.8 | .... | .... | .... | .... | .... | .... | .... | .... | 0.142 | Below—70 | 124 | .... |
| 305 | 14 | 754 | 305 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 327 | 16 | | 327 | 14 | 305 | 48.4 | 0.88 | 0.74 | 0.51 | .... | .... | .... | 188 | 0.063 | .... | .... | .... | 127† |
| 354 | 18 | | 354 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 380 | 20 | | 380 | 18 | 354 | 44.1 | .... | .... | .... | .... | .... | .... | .... | .... | 0.154 | Below—70 | 125 | 130 |
| 406 | 22 | | 406 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 428 | 24 | | 428 | 22 | 406 | 40.5 | 1.46 | 1.16 | 0.73 | .... | .... | .... | 333 | 0.19 | .... | .... | .... | 157† |
| 205 | 26 | | 430 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 218 | 28 | | 447 | 26 | 430 | 37.0 | .... | .... | .... | .... | .... | .... | .... | .... | 0.257 | —65 | 134 | .... |
| 238 | 30 | | 474 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 260 | 32 | | 503 | 30 | 474 | 35.7 | 2.34 | 1.76 | 1.01 | 33.9 | .... | .... | 553 | 0.43 | .... | .... | .... | 179† |
| 276 | 34 | 10 | 523 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 300 | 36 | | 555 | 34 | 523 | 32.9 | .... | .... | .... | .... | .... | .... | .... | .... | 0.628 | —15 | 142 | .... |
| 320 | 40 | | 579 | 38 | .... | 32.5 | 4.74 | 3.22 | 1.56 | 41.5 | 36.8 | .... | .... | 0.79 | .... | .... | .... | 211† |
| 328 | 42 | | 590 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 340 | 44 | | 604 | 42 | 590 | 31.4 | .... | .... | .... | .... | .... | .... | .... | .... | 0.995 | +15 | 159 | .... |
| 328 | 47 | | 705 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 327 | 49 | | 704 | 47 | 705 | 26.6 | 14.53 | 8.27 | 2.99 | 75.4 | 53.0 | 36.2 | .... | 1.19 | .... | .... | .... | 282† |
| 346 | 51 | 0.85 | 730 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 363 | 53 | | 753 | 51 | 730 | 24.8 | .... | .... | .... | .... | .... | .... | .... | .... | 1.015 | +60 | 159 | .... |
| 374 | 55 | | 768 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 386 | 57 | | 776 | 55 | 768 | 23.3 | 35.0 | 17.10 | 4.83 | 163.2 | 85.7 | 42.9 | .... | 1.25 | .... | .... | .... | 308 |
| 439 | 59 | | 841 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 452 | 61 | | 861 | 59 | 841 | 21.9 | .... | .... | .... | .... | .... | .... | .... | .... | 1.225 | +80 | 169 | 380† |
| 479 | 63 | 1.05 | 897 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 492 | 65 | | 912 | 63 | 897 | 19.8 | 162 | 59.3 | 10.53 | 747 | 275 | 61.0 | .... | 1.33 | .... | .... | .... | 410† |
| 523 | 67 | | 955 | 66 | 933 | 19.1 | .... | .... | .... | 1,35)† | 447 | 74.9 | .... | .... | 1.210 | .... | 172 | .... |
| Bottoms | 33 | .... | .... | .... | .... | 8.3 | Flash point (Cleveland), 565 °F. | .... | .... | .... | .... | 6,600 | .... | 1.97 | .... | +110 | (Conradson carbon residue, 15.36 percent) | |

* Converted from kinematic viscosity at 100 °F. † Estimated.

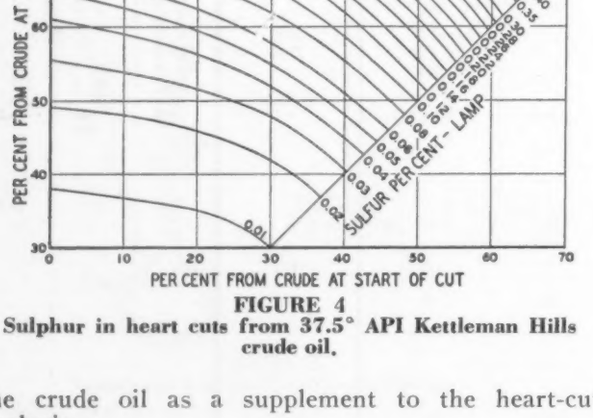


**FIGURE 4**

**Sulphur in heart cuts from 37.5° API Kettleman Hills crude oil.**

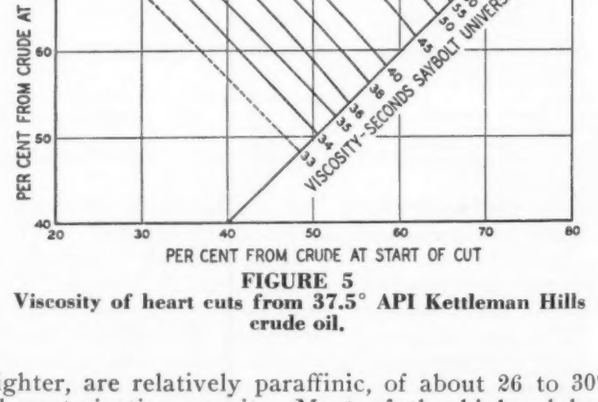


**FIGURE 5**

**Viscosity of heart cuts from 37.5° API Kettleman Hills crude oil.**

the crude oil as a supplement to the heart-cut analysis.

## Characteristics of Crude Oils

No truly satisfactory method exists for grouping or classifying California crude oils among themselves. If they are classified according to any one property, the resulting grouping is unsatisfactory from the standpoint of several other important properties.

A few approximate generalizations can be stated, however. For example, most of the more naphthenic crude oils, i.e., with characterization gravity of 23° or lower, are of 27° API gravity or heavier. Similarly, all light California crude oils, 28° API or lighter, are relatively paraffinic, of about 26 to 30° characterization gravity. Most of the high-sulphur crude oils are heavier than about 20° API; however, sulphur content bears little relation to the degree of paraffinicity, and many relatively heavy crude oils are of low sulphur content.

The crude oils are sometimes classified as "refinable" and "non-refinable." In this paper refinable crude oils are assumed to contain more than about 3 percent of straight-run gasoline; the non-refinable ones, less than 3 percent. For certain purposes this grouping is convenient; however, it bears little relation to any other property of the stocks. For example, the refinable crude oils may be paraffinic or naphthenic, of high sulphur content or of low sul-

phur content, and waxy or non-waxy. The refinable crude oils are usually those of higher API gravity; however, API gravity is not a measure of so-called refinability. For example, a 16°-API-gravity California crude oil may have a gasoline content ranging from 0 to 20 percent, and may be either non-refinable or refinable.

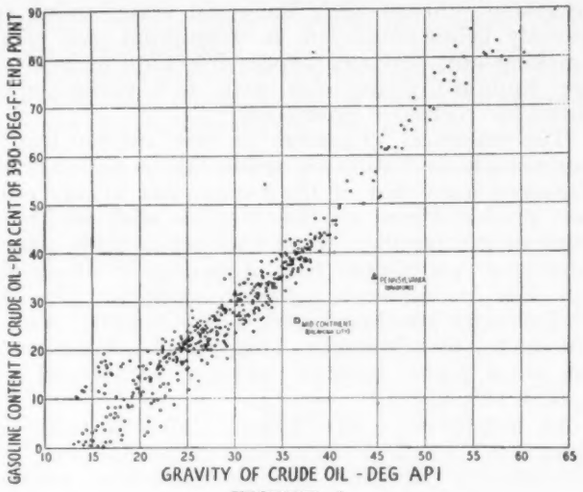


**FIGURE 6**
**Gasoline content of California crude oils as a function of gravity.**

Crude oils from the San Joaquin Valley fall into two main groups, produced in about equal volume. The first group includes the heavier and more naphthenic oils, most of them ranging in API gravity between approximately 14 and 25°, and in characterization gravity from 19 to 23°. Up to about 1930, most of the valley production was of this type. Midway-Maricopa district produces oil representative of this type.

The second group includes lighter and more paraffinic crude oils, most of them lighter than about 30° API gravity, and with a characterization gravity between 26 and 30°. Kettleman, Coalinga Eocene, and Coles Levee are representative. Most of the production in this group is from fields opened in recent years—especially from deeper, older geologic zones.

The relationship to geologic age appears to be general throughout California. Deep wells producing from geologically older strata usually yield lighter, more paraffinic oil of lower sulphur content than do shallower wells in the same field producing from geologically younger rock.

Typical crude oil from the Southern California fields is intermediate in gravity and paraffinicity between the two main San Joaquin Valley types, but is of appreciably higher sulphur content than is either of the two. However, stocks from the different Southern California fields differ widely among themselves in gravity, gasoline content, paraffinicity, and sulphur content.

Most of the crude oil produced in the California coastal area resembles the lighter group of oils produced in the San Joaquin Valley. However, the coastal area also produces considerable oil of markedly different types, such as the high-sulphur low-gravity Santa Maria Valley crude oil.

## Gravity

California crude oils range in API gravity from about 6 to 60°. The heaviest ones are essentially asphalt, and the lightest may contain more than 85 percent of gasoline with an end point of 390° F. Most of the production in the state is within the API gravity range of 18 to 38°. The weighted-average production in the entire state is of about 27 to 28° API.

As compared to this, most Pennsylvania crude oils are of about 40 to 45° API, and Mid-Continent about 35 to 40° API. East Texas averages around 40; West Texas is in the range of about 30 to 40, and the two Gulf Coastal types probably are in the ranges 19 to 25, and 30 to 40, respectively. Therefore, California crude oils, on the average, are substantially heavier than are most crude oils produced east of the Rockies.

## Volatility

California crude oils differ widely among themselves in volatility. Some are more than 85 percent asphalt, and some contain more than 85 percent gasoline.

Figure 6 shows the relation between the API gravity of about 500 different California crude oils and their gasoline content. As shown in Figure 6, the lighter crude oils usually contain the most gasoline; however, the gravity of a given oil is not a satisfactory measure of its gasoline content. For example, crude oil of 16° API gravity may contain from 0 to about 20 percent gasoline—depending upon its source, boiling characteristics, and paraffinicity.

Points corresponding to typical Pennsylvania and Mid-Continent crude oils are included in Figure 6. These oils contain substantially less gasoline than do California crude oils of the same gravity, due to their more paraffinic character and lower asphalt content.

The yield vs. true-boiling-point relationship for several typical California and Eastern crude oils is shown in Figure 7. In this regard the different California oils differ markedly among themselves. The relative percentage of oil boiling in different ranges

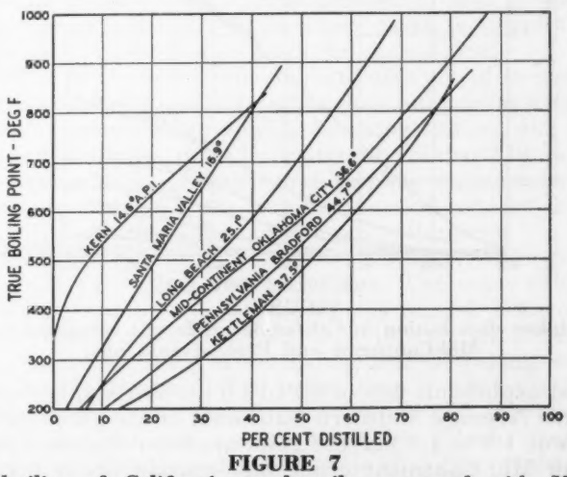


**FIGURE 7**
**Volatility of California crude oils compared with Mid-Continent and Pennsylvania oils.**

varies considerably, and may or may not be similar to that in Mid-Continent, Pennsylvania, and Texas crude oils.

## Viscosity

The heavier California crude oils are substantially more viscous than are most Pennsylvania, Mid-Continent, or Texas crude oils, due primarily to their higher boiling points and higher asphalt content. This leads to a problem in pipe-line transportation, due to the high pressure drop. Transportation by

tanker has been adopted in many cases to avoid this difficulty.

California oils of a given boiling range are appreciably more viscous than are Pennsylvania or Mid-Continent oils of the same boiling range. This difference is in accord with the difference in paraffinicity. For example, gas oils with an average boiling point of 700° F from Pennsylvania, Mid-Continent, Kettleman Hills (California), and Midway (California) crude oils have a Saybolt-Universal viscosity, respectively, of 66, 71, 74, and 120 seconds at 100° F.

Residuum stocks from California crude oils are substantially heavier, both in gravity and viscosity, than are corresponding residuums from Eastern crude oils. For example, residuums following kerosine distillate from Mid-Continent, Kettleman Hills, and Midway crude oils have, respectively, an API gravity of approximately 29, 23, and 15°, and a Saybolt-Universal viscosity of 90, 100, and 770 seconds at 130° F.

Wax-free lubricating-oil distillate from California crude oils is of a viscosity index ranging from about —200 to +30. Solvent refining and dewaxing of distillates or residuums from selected crude oils, however, produce high-quality lubricants of 90 to 100 viscosity index.

### Sulphur Content

The sulphur content of California crude oils is, in most cases, far higher than that of Pennsylvania and Mid-Continent oils, and substantially higher than that of most Texas oils. California crude oils range in sulphur content from about 0.1 to 6 percent. San Joaquin Valley crude oils fall into two groups: paraffinic oils of about 0.3 to 0.5 percent sulphur content,

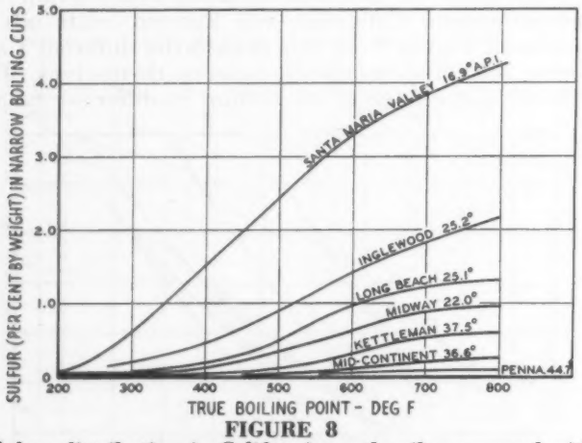


**FIGURE 8**

**Sulphur distribution in California crude oils compared with Mid-Continent and Pennsylvania oils.**

and naphthenic oils of 0.7 to 1.0 percent sulphur content. Average Southern California crude oil contains about 1.0 to 1.5 percent sulphur. Most Pennsylvania and Mid-Continent crude oils contain about 0.1 to 0.3 percent sulphur, and those from Texas perhaps 0.2 to 3.0 percent.

The sulphur distribution in several different crude oils is shown in Figure 8. Kettleman Hills is classified as of low sulphur content; yet distillates therefrom contain two to five times as much sulphur as do corresponding Pennsylvania and Mid-Continent distillates, and about the same amount as do distillates from East Texas crude oil. Distillates from high-sulphur California crude oils, such as Santa Maria Valley and Inglewood, may contain as much as 1 to 4 percent sulphur, or perhaps 20 times as much as does the corresponding distillate from Mid-Continent crude oil.

Residuum cracking stocks processed in California are usually of high sulphur content, ranging from about 0.9 to 2.0 percent, and averaging about 1.3 to 1.7 percent. They are far more corrosive to cracking equipment than are most Mid-Continent and Texas stocks. Vessels and lines must be protected against corrosion—chrome-alloy lines and vessel lining frequently being employed. A substantial part of the cracking-unit furnaces processing California stocks are equipped throughout with 18-8 chrome-nickel tubes for corrosion protection.

The chemical character of the sulphur-bearing compounds in California crude oils is substantially different from that of the compounds in any crude oils produced east of the Rockies with which the authors are familiar. Most California crude oils, as produced, are almost free of hydrogen sulfide and are low in mercaptan-sulphur content. The raw straight-run gasolines usually are slightly sour to the doctor test, however. Texas stocks, for example, are much higher both in hydrogen sulfide and mercaptan sulphur.

In low-pressure distillation, California oils produce much less hydrogen sulfide than do Texas oils. Cracking of California residuum, however, produces considerable hydrogen sulfide and mercaptan sulphur, as well as considerable heavier sulphur compounds not of the mercaptan type.

The sulphur compounds in California cracking stock appear to be more stable to heat than are those in Texas oils. On cracking, the sulphur in Texas oil tends to form hydrogen sulfide and to appear in the gas—producing relatively low-sulphur naphtha. The sulphur compounds in California oil tend to split into compounds of intermediate boiling range and appear in the naphtha, which is of relatively high sulphur content.

A few crude oils are known in which the sulphur compounds appear to be more stable than are those in California stocks. Crude oil from Bahrein Island (Persian Gulf) and especially that from the Cut Bank field, Montana, are examples. On cracking residuums from these crude oils, the sulphur appears to concentrate in the cracked residuum, producing cracked naphtha of relatively low sulphur content.

### Paraffinicity

California crude oils are substantially less paraffinic than are Pennsylvania, Mid-Continent, East Texas, or West Texas crude oils. Some of the heavy Gulf Coast oils are, however, about equal in paraffinicity to California stocks.

Crude oils range in paraffinicity from certain of the highly aromatic Borneo crude oils, having a characterization gravity of approximately 15°, to highly paraffinic crudes, such as certain Pennsylvania, Michigan, and Louisiana stocks, which have a characterization gravity ranging from approximately 36 to 38°. California crude oils are grouped about half way between these two extremes, having characterization gravities ranging from 19 to 30°. Kettleman Hills, a rather paraffinic California crude oil, has a characterization gravity of approximately 29°; Midway, a rather non-paraffinic California oil, has a characterization gravity of approximately 22°. Average Southern California stocks are intermediate—characterization gravity ranging from 24 to 26°. Mid-Continent and East Texas crude oils range in characterization

gravity from approximately 30 to 33°, and Pennsylvania from about 34 to 36°.

With a few unimportant exceptions, all California oils owe their non-paraffinic character to the presence of naphthenic compounds. Their naphthene content is considerably higher than that of Eastern oils; their aromatic content is low, and is not greatly different from that of Eastern oils. Certain Borneo crude oils are far more aromatic in character than are any California oils.

As shown in Figures 9 and 10, the paraffinicity of California crude oils may vary considerably, depending upon the boiling range. For example, gasoline

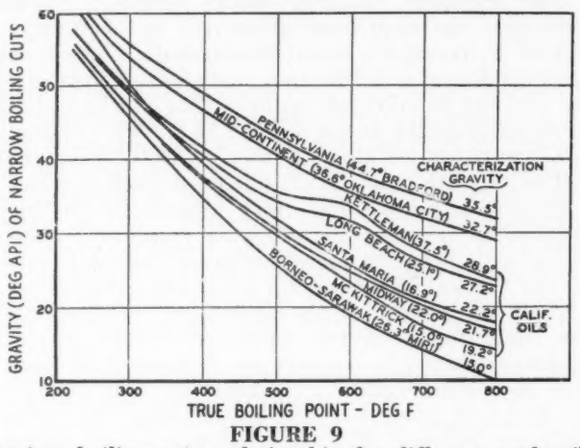
GRAVITY (DEG API) OF NARROW BOILING CUTS
TRUE BOILING POINT - DEG F
CHARACTERIZATION GRAVITY
PENNSYLVANIA (44.7° BRADFORD) 35.5°
MID-CONTINENT (36.6° OKLAHOMA CITY) 32.7°
KETTLEMAN (37.5°) 28.9°
LONG BEACH (23.1°) 27.2°
SANTA MARIA (16.9°) 22.2°
MIDWAY (22.0°) 21.7°
MC KITTRICK (15.0°) 19.2°
BORNEO-SARAWAK (26.3° MIRI) 15.0°
CALIF. OILS

**FIGURE 9**
**Gravity—boiling point relationship for different crude oils.**

from Santa Maria Valley crude oil is quite paraffinic; whereas heavy gas oil and asphalt therefrom are quite naphthenic.

The naphthenic character of California crude oils is reflected in the high octane number of the straight-run gasolines. The gasolines with an end point of 390° F, after they have been blended with natural gasoline to obtain 170° F at the 20-percent point, usually range in octane number from 60 to 73 CFR motor method. A large proportion of them is in the upper part of this range. Corresponding gasolines from the Mid-Continent, East Texas, and West Texas are usually of about 50 to 60 octane number.

The naphthenic character of California stocks also results in production of cracked and reformed gasolines of relatively high octane number.

The wax content of California crude oils varies greatly. The naphthenic crudes, especially those of low API gravity, are usually low in wax and of low pour point. Residuums therefrom are usually of a pour point below about +10° F. The light, paraffinic California crude oils usually contain 2 to 4 percent wax, residuums therefrom usually being of a pour point above +60° F. The wax is concentrated in the heavy-gas-oil and lubricating-oil distillate range. The asphalt from these crude oils is waxy, but less waxy than is the heavy gas oil.

Naphthenic acids are present in California crude oils throughout the boiling range from kerosine to asphalt. A considerable volume of naphthenic acid is recovered from the different distillates for special chemical manufacture.

Cracked naphtha from California charging stocks contains a considerable amount of nitrogen bases and phenolic compounds. Nitrogen bases can be recovered from the sulphuric acid used in finishing cracked naphthas. A substantial volume of heavy substituted phenols is recovered by caustic-washing of cracked naphthas, neutralizing, and distilling.

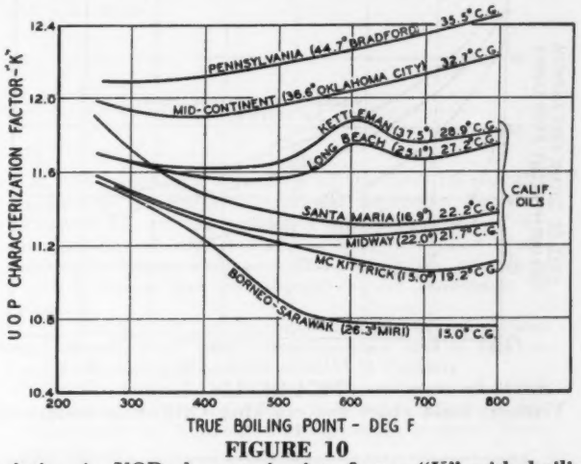
U O P CHARACTERIZATION FACTOR - "K"
TRUE BOILING POINT - DEG F
PENNSYLVANIA (44.7° BRADFORD) 35.5° C.G.
MID-CONTINENT (36.6° OKLAHOMA CITY) 32.7° C.G.
KETTLEMAN (37.5°) 28.9° C.G.
LONG BEACH (23.1°) 27.2° C.G.
SANTA MARIA (16.9°) 22.2° C.G.
MIDWAY (22.0°) 21.7° C.G.
MC KITTRICK (15.0°) 19.2° C.G.
BORNEO-SARAWAK (26.3° MIRI) 15.0° C.G.
CALIF. OILS

**FIGURE 10**
**Variation in UOP characterization factor "K" with boiling point.**

California oils are of higher sulphur content, and are more naphthenic, darker in color, and less color-stable, than most Eastern oils. These factors lead to important differences in the refining processes required.

Most straight-run gasolines from California crude oils are treated with a small amount of acid to meet color requirements, and in many cases to lower the sulphur content and to meet the doctor test.

Most of the raw kerosine distillates are of unsatisfactory burning quality due to their sulphur and aromatic content. High-quality kerosine can be, and is, made by sulphur-dioxide treatment, followed by acid treatment to meet color and sulphur requirements. The top cut from the sulphur-dioxide extract is a valuable source of low-aniline-point thinners.

Raw lubricating-oil distillate from all California crude oils is of low viscosity index. The waxy crude oils yield the best distillates in this regard, but even they seldom exceed +30 viscosity index after dewaxing. In a few cases acid treating and dewaxing will produce lubricating oil of better than 90 viscosity index. Most of the high-quality motor oils manufactured in California are produced by solvent treatment and dewaxing of waxy crude oils. The resulting product is of the highest quality.

A large volume of heavy fuel oil, composed of

**TABLE 3**
**Reforming of straight-run naphtha.**

| Crude Oil | Midway, California | Kettleman Hills, California | East Texas | Oklahoma City |
|---|---|---|---|---|
| Reformer charge: | | | | |
| Boiling range, °F | 250–400 | 250–400 | 250–400 | 250–400 |
| Octane No., CFR motor method | 63.5 | 48 | 46 | 36 |
| Raw reformed gasoline (end point, 400 °F; vapor pressure, 8 lb.): | | | | |
| Yield, percent by volume | 80 | 80 | 80 | 80 |
| Octane No., CFR motor method | 76 | 73.5 | 73 | 70 |

cracked residuum and crude residuum, is produced in California refineries. This stock is of low API gravity, high viscosity, high sulphur content, and may be of a high pour point. Blending with 10 to 20 percent of light gas oil is necessary to meet viscosity and gravity requirements. Viscosity and gravity are substantially less critical in refineries processing crude oils produced east of the Rockies, residuums from most of which are substantially lighter both in gravity and viscosity.

Straight-run gasolines from California crude oils respond readily to thermal reforming. Table 3 shows results of reforming straight-run naphtha from different typical California and Eastern crude oils.

The fundamental yield-octane-number relationship is believed to be the same for both California and Eastern stocks; however, the California oils produce reformed gasoline of markedly higher knock rating, because the charging stocks are of higher octane number than are those from most Eastern crude oils.

Raw reformed gasoline from California oils is usually of lower color than is that made from most Eastern oils. In most cases treatment is required to meet color and color-stability requirements.

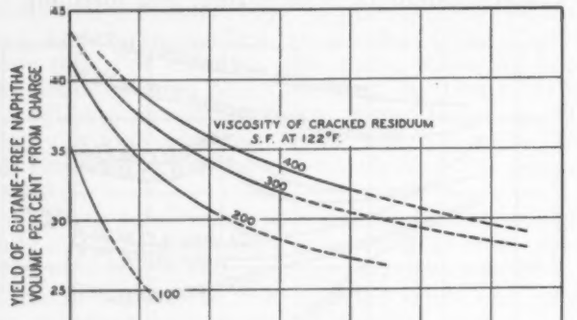


**FIGURE 11**
**Viscosity-yield chart for cracking California residuum.**




**FIGURE 12**
**Sulphur relationship in cracking California residuum.**

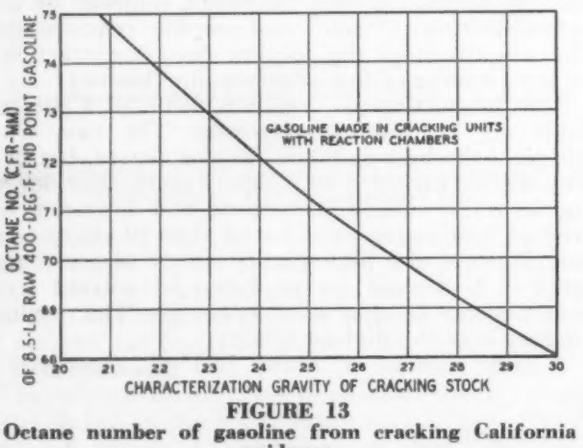


**FIGURE 13**
**Octane number of gasoline from cracking California residuum.**

## Cracking

Residuum, rather than gas oil, is charged to most cracking units processing California oil. Gas-oil cracking is usually uneconomical, because the required vacuum - distillation and asphalt - viscosity - breaking steps are unduly expensive.

The residuum cracking stocks range in Saybolt-Universal viscosity from about 125 to 2,500 seconds at 130° F, averaging about 800 seconds. The viscosity has been found to be the most satisfactory measure of the yield of gasoline or naphtha that can be obtained from the cracking stock. Figure 11 shows a viscosity-yield chart for cracking California residuum in single-coil units, with reaction chambers of moderate size.

Gravity is not a satisfactory measure of the yields obtainable in cracking California residuums because of the wide range in paraffinicity and asphalt content of the stocks. However, all California residuums of a given viscosity produce essentially the same naphtha yield for a given cracked-residuum viscosity, whatever their gravity may be. A yield chart such as that shown in Figure 11 is, therefore, of marked utility in plant operation and in planning the refinery viscosity balance. Viscosity balance is an important problem in California refineries, due to the high viscosity of most of the oils processed.

The charging stocks and cracked residuums are substantially heavier and contain more asphalt than is the case when processing most Eastern oils. The cracking process occurs more in the liquid phase than is the case in the East, and coking is more severe.

Figure 12 shows the relation between sulphur content of charging stock and cracked naphtha when processing California residuums. A large proportion of the charging stock processed in California has a sulphur content of aproximately 1.5 percent, and produces cracked naphtha with a sulphur content of about 0.8 percent. Most of the cracked naphtha is acid-treated to reduce the sulphur content of the gasoline to a satisfactory value, and to produce good color.

Sulphur presents a far more serious problem in cracking California oils than is the case in the East.

Most California cracking stocks produce cracked gasoline of substantially higher octane number than do cracking stocks from crude oils produced in the rest of the United States. This is due to the highly naphthenic character of the stocks. Figure 13 shows the relationship between characterization gravity of the charging stock and octane number of the raw cracked gasoline produced therefrom, in single-coil units equipped with reaction chambers of moderate size and fractionating columns operating at essentially the same pressure as exists in the cracking zone. As shown in Figure 13, cracking stock from Midway crude oil (characterization gravity, 22°) produces raw gasoline of about 74 octane number, CFR motor method; whereas, a Mid-Continent crude oil, with a characterization gravity of approximately 32°, would produce gasoline of about 67 octane number.

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# The Synthesis and Properties of Hydrocarbons of High Molecular Weight

J. N. COSBY and L. H. SUTHERLAND
The Pennsylvania State College

**THIS paper is a summary of the first 16 months' work on American Petroleum Institute Research Project 42, on the synthesis and properties of hydrocarbons of high molecular weight, at The Pennsylvania State College. The synthesis of these hydrocarbons had as objectives the obtaining of data:**

**1. To permit conclusions on the effect of chemical structure on physical properties in the higher-molecular-weight ranges.**

**2. To furnish data on hydrocarbons of high molecular weight of value in identification of hydrocarbons or hydrocarbon mixtures isolated from petroleum.**

**3. To afford data useful in chemical-engineering calculations on petroleum fractions above gasoline.**

**4. To provide the industry with reliable methods of preparation and purification of hydrocarbons of high molecular weight which will be useful guides when the need arises for preparing larger quantities of such hydrocarbons.**

**Twenty-two hydrocarbons ranging in molecular weight from 344 to 450 have been prepared, with a purity of 95 percent or better. The following physical properties have been determined on each of these hydrocarbons:**

**1. Kinematic viscosity at 68, 100, 140, and 210° F.**

**2. Kinematic viscosity index by the Dean and Davis method.**

**3. Density at 68, 100, 140, and 210° F.; gravity, in ° API, calculated.**

**4. Melting point taken from melting curve.**

**5. Boiling points from vapor-pressure curve over the range 0.5 mm. to 5.0 mm.**

**6. Heat of vaporization, calculated for the range 0.5- to 5.0-mm. pressure.**

**7. Refractive index at 20, 30, and 40° C.**

**8. Specific refraction, calculated at 20° C.**

**9. Mean and specific dispersion at 20° C. Measurements of other physical properties are in progress.**

**Several generalizations have been pointed out in the relation of physical properties to structure. Application of the data presented in this paper has been made in checking the work of Kurtz on molecular volume.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 5, 1941, by C. R. Wagner, The Pure Oil Company, Chicago; member of Advisory Committee, API Research Project 42, of which committee F. C. Whitmore is director.**

THE need for a knowledge of the properties of pure hydrocarbons of high molecular weight in establishing the chemical composition of lubricating oils has been recognized. However, the time and effort required to prepare the large number of compounds and to determine their physical properties with care has limited the investigations. To correct this situation the American Petroleum Institute has initiated Research Project 42 at The Pennsylvania State College under the direction of Dean F. C. Whitmore.

The primary objectives of the project are to make and to determine the properties of a suitable number of carefully selected hydrocarbons in the range of 25 to 60 carbon atoms. The data obtained from this work should permit more exact conclusions to be drawn concerning the effect of chemical structure on the physical properties in the lubricant range. The data should aid in making generalizations that will be of value in the identification of hydrocarbons or hydrocarbon mixtures isolated from petroleum. The work will supply information needed in chemical-engineering calculations. When a need arises for reliable methods of preparation and purification of large quantities of hydrocarbons in this range, they will be available to the industry.

## History

Although the chemical structure of lubricating oil has been the subject of detailed study since the extensive researches of Mabery,[1] no exact knowledge could be gained before the synthesis of pure hydrocarbons in this range. Hugel[2] was the first to study the problem from this viewpoint. Although his compounds were of questionable purity, he did prepare various types of hydrocarbons in the high-molecular-weight range and tried to correlate their physical properties with their chemical structures.

From that time the study has made considerable advance due to the work of Mikeska.[3]* In his very systematic investigations involving the synthesis of more than 50 hydrocarbons of high molecular weight, he did much to lay a sound foundation for this field. Of course, much still remains to be done.

To serve as a review of just what is being done in the field of hydrocarbons of high molecular weight, the staff of Project 42 made a survey of the compounds in this field, given in *Chemical Abstracts* for the five years 1935-39. The list includes 216 different hydrocarbons containing more than 24 carbon atoms, for which a structure and at least one physical property were given. For only eight compounds other than those prepared by Mikeska were properties reported that could be of use to the peroleum industry. In most cases only the melting point was given. Even the few boiling points obviously may be in error by as much as 10°.

* As a member of the advisory committee, Dr. Mikeska has been most helpful in the work on Project 42.

Accurate proof of structure, and even adequate descriptions of the methods of synthesis, were usually lacking.

This literature study definitely showed the lack of current interest by chemists in this problem. In the last year, however, there have been a few papers published with the purpose of studying the relationship of structure to properties of hydrocarbons of high molecular weight, but in no case was the range of properties wide enough for effective use by the petroleum industry. Inasmuch as all the research workers in the field of hydrocarbons of high molecular weight, other than ourselves, are Europeans, it is apparent that world conditions will limit extended interest in this subject in the near future.

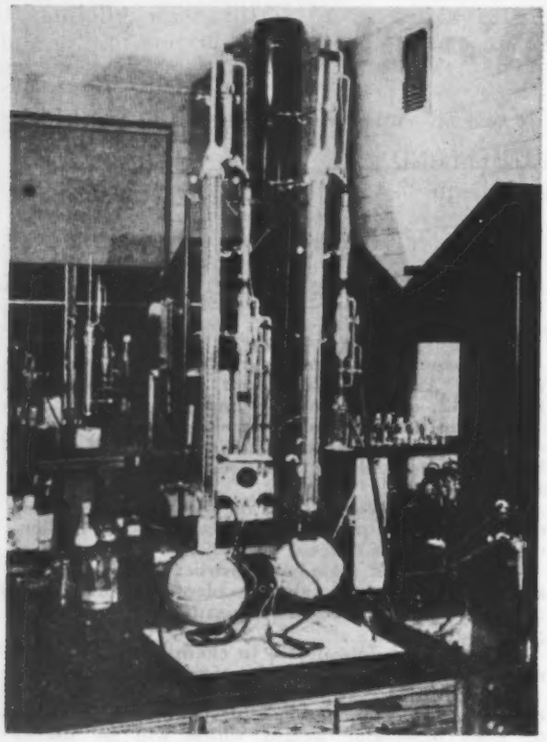


**FIGURE 1**
**Set of Medium-Size Laboratory Columns for the Purification of Intermediates (25-35 Plates).**

The compounds reported in this paper, with the exception of one, have not been prepared before. The synthesis of this compound, 11-*n*decyldocosane (PSC 7), came to our attention after our compound had been prepared. The properties reported by the Russian workers [4] agree well with ours.

### Compounds Prepared and Their Properties

For the purpose of summary and comparison, the 22 compounds completed in the first 16 months of work on Project 42 are listed in Table 1. These compounds have been given *PSC* numbers, which signifies that they have met the requirements set by the advisory committee. These requirements are: that the purity shall be 95 percent or better; that more than 100 grams of material of this purity be made; and that most of the important properties have been obtained. The properties listed are those determined thus far. Other physical properties are being determined or planned.

In the table, expressions such as "$C_{10}$" mean a straight unbranched, saturated chain of 10 carbon atoms with the appropriate hydrogens.

### Methods of Preparation

The general procedure in the preparation of the hydrocarbons has been to pick reactions in which isomerization does not occur and in which the byproducts or unreacted intermediates differ in properties to such an extent that their separation from the hydrocarbons is accomplished easily. However, there is usually no way of eliminating completely isomers formed from impurities in the intermediates. This fact has not been recognized sufficiently in this field. Therefore, we have taken every precaution to obtain the greatest possible purity in our intermediates.

In order to avoid trouble from possible side reactions, the compounds for synthesis were picked in such a manner that the byproducts could be detected easily and eliminated.

We have found the Grignard preparation of alcohols, followed by dehydration and hydrogenation, most satisfactory. This procedure has been used with all but one of the compounds reported in this paper. Although the Grignard reaction is by no means simple, [5] it does not give rearrangements in the reactions used by us. Moreover, this reaction is well adapted to large-scale laboratory runs and, in general, the overall yields are good.

In contrast, the Friedel-Crafts and Wurtz-Fittig reactions, methods frequently used in this field, are not so successful in avoiding rearrangement and in the production of difficultly separable byproducts. The Friedel-Crafts synthesis, followed by Clemmensen reduction, gives rise to isomers in many cases; it is time-consuming, with yield none too good; and it has been exhausted largely by earlier workers. Likewise the Wurtz-Fittig method has limitations. The yields are generally poor, and the number of compounds that may be prepared definitely is limited.

**FIGURE 2**
**Set of Large-Size Laboratory Columns for the Purification of Intermediates (30-40 Plates).**

After choosing the compound to be prepared and the method of synthesis, the problem becomes one of ob-

taining pure intermediates. The importance of this point cannot be overestimated. For the liquids and low-melting solids two sets of columns (Figure 1 and Figure 2), with the efficiency of 30 to 40 theoretical plates, have been used. With the crystalline solids, extensive use has

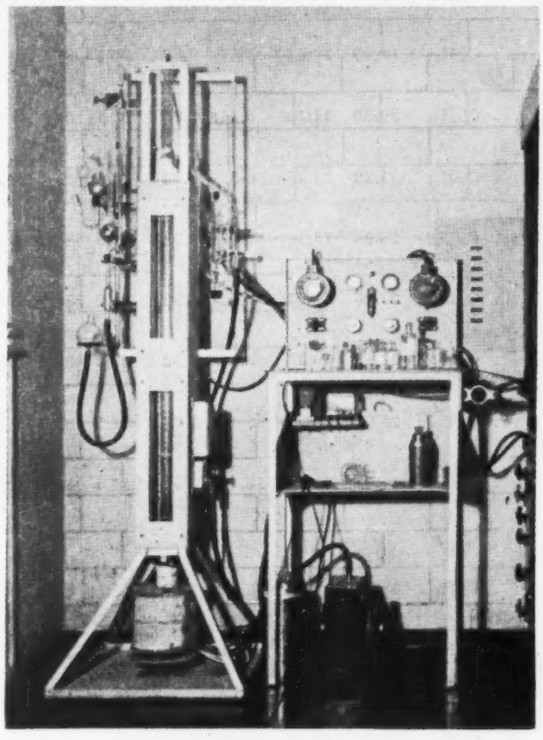


**FIGURE 3**
**High-Vacuum Column for the Distillation of Hydrocarbons of High Molecular Weight (4-6 Plates).**

been made of fractional crystallization. By the two methods we have obtained a high degree of purity in all our intermediates.

After having obtained the pure starting materials, each step of the synthesis was followed by careful purification. In most cases distillation and selective adsorption on silica gel proved most useful. In order to be able to distill these very high-boiling materials, a special column was designed and built (Figure 3). Although an efficiency of only 4 to 5 theoretical plates can be obtained with such a column, its extremely low pressure drop makes possible distillation without decomposition of compounds containing at least 35 carbon atoms at pressures down to 0.2 mm. The traces of impurities not separated by distillation were removed by the silica-gel adsorption tubes. These have been employed extensively with very satisfactory results (Figure 4). As yet, general use has not been made of solvent extraction or fractional crystallization of the hydrocarbons; but both methods are being studied, and show much promise.

Additional data on the synthesis of the hydrocarbons and the equipment are outside the scope of this paper. This information will be published soon in appropriate chemical journals.

## Criteria of Purity

This phase of the research is of the greatest importance, and in many respects the most difficult. A complete treatment of the subject is beyond the limits of this paper. The general procedure has been to purify the compounds as far as possible and then, with the methods available, to establish their degree of purity.

The best method to give positive information is the use of the time-temperature melting curve. In most cases this allows a very close estimate of the purity. Factors complicating or making impossible the use of this procedure are geometrical or optical isomerism, changes in crystalline structure during melting, and the formation of non-crystalline glasses.

There are additional checks on the purity that must be depended upon when time-temperature melting curves cannot be used. These show the presence of impurities that differ in molecular weight or type, but do not eliminate the possibility of isomers. Of these the distillation curve, molecular refraction, effect of passing through silica gel, and solvent extraction are the most important.

The final distillation of the hydrocarbon through our high-vacuum column furnishes a critical test of the preparation and its product. For a hydrocarbon to receive a PSC number, we require that at least 60 percent of the distillate from this column have a refractive index constant to 0.0002. Such constant material is given the PSC number. With most compounds, the results are better than this, 85 to 95 percent of the distillate being constant in refractive index to 0.0001. These data on purity are checked, by viscosity and density measurements on the fractions.

Molecular refraction is most valuable in detecting the presence of impurities of different molecular type. This also supplies data on structure proof of the finished hydrocarbons. Specific refraction, a closely related function, is used widely in determining the character of hydrocarbon mixtures such as those isolated from petroleum.

Silica gel is used for removing traces of impurities both with intermediates and semi-finished products. It is employed also to check the purity of the finished hydrocarbons. The course of adsorption is followed by refractive-index measurements which definitely show the presence or absence of impurities of different polar type. Solvent extraction gives the same type of data,

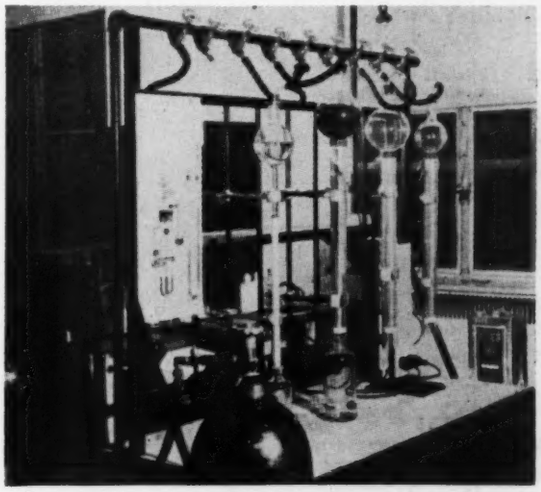


**FIGURE 4**
**Silica-Gel Adsorption Tubes**

but with our present methods this is much more laborious. It is being developed, however, because it is more sensitive to traces of impurities.

## Physical Properties

The problem of obtaining accurate physical constants is as important as the purity of the hydrocarbons. Although only approximately half of the ultimate number of properties has been determined, much headway has

## TABLE 1
### The Compounds and their Properties

| PSC No. | Name of Structure | Empirical Formula | Kinematic Viscosity (Centistokes) at: 68 Deg F | 100 Deg F | 140 Deg F | 210 Deg F | Viscosity (Saybolt-Universal) (Calculated) At 100 Deg F (Seconds) | At 210 Deg F (Seconds) | Kinematic Viscosity Index (Dean and Davis) |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 11-*n*Butyldocosane $C_{10}—\underset{\displaystyle C_4}{\overset{\displaystyle |}{C}}—C_{11}$ | $C_{26}H_{54}$ | 19.08 | 10.41 | 5.78 | 2.78 | 60.2 | 35.5 | 124 |
| 2. | 9-*n*Butyldocosane $C_8—\underset{\displaystyle C_4}{\overset{\displaystyle |}{C}}—C_{13}$ | $C_{26}H_{54}$ | 19.46 | 10.61 | 5.87 | 2.83 | 60.9 | 35.7 | 128 |
| 3. | 7-*n*Butyldocosane $C_6—\underset{\displaystyle C_4}{\overset{\displaystyle |}{C}}—C_{15}$ | $C_{26}H_{54}$ | 20.50 | 11.10 | 6.11 | 2.93 | 62.7 | 36.0 | 131 |
| 4. | 5-*n*Butyldocosane $C_4—\underset{\displaystyle C_4}{\overset{\displaystyle |}{C}}—C_{17}$ | $C_{26}H_{54}$ | 21.29 | 11.48 | 6.35 | 3.03 | 64.0 | 36.4 | 138 |
| 5. | 7-*n*Hexyldocosane $C_6—\underset{\displaystyle C_6}{\overset{\displaystyle |}{C}}—C_{13}$ | $C_{28}H_{58}$ | 24.96 | 13.10 | 7.17 | 3.33 | 70.0 | 37.3 | 144 |
| 6. | 9-*n*Octyldocosane $C_8—\underset{\displaystyle C_6}{\overset{\displaystyle |}{C}}—C_{13}$ | $C_{30}H_{62}$ | 27.43 | 14.43 | 7.73 | 3.56 | 75.0 | 38.1 | 148 |
| 7. | 11-*n*Decyldocosane $C_{10}—\underset{\displaystyle C_{10}}{\overset{\displaystyle |}{C}}—C_{11}$ | $C_{32}H_{66}$ | 31.85 | 16.53 | 8.73 | 3.92 | 83.2 | 39.1 | 155 |
| 8. | 11-*n*Decylheneicosane $C_{10}—\underset{\displaystyle C_{10}}{\overset{\displaystyle |}{C}}—C_{10}$ | $C_{31}H_{64}$ | 29.07 | 15.12 | 8.08 | 3.67 | 77.7 | 38.2 | 149 |
| 62. | 11-a-Decalinheneicosane $C_{10}—\underset{\displaystyle \text{Decalin}}{\overset{\displaystyle |}{C}}—C_{10}$ | $C_{31}H_{60}$ | 117.01 | 45.67 | 18.45 | 6.36 | 211.5 | 47.5 | 95 |
| 27. | 11-*n*Amylheneicosane $C_{10}—\underset{\displaystyle C_5}{\overset{\displaystyle |}{C}}—C_{10}$ | $C_{26}H_{54}$ | 18.53 | 10.08 | 5.63 | 2.73 | 59.1 | 35.4 | 125 |
| 53. | 11-(3-Pentyl)-heneicosane $C_{10}—\underset{\displaystyle C}{\overset{\displaystyle |}{C}}—C_{10}$ (C: $C_2$, $C_2$) | $C_{26}H_{54}$ | 19.25 | 10.39 | 5.71 | 2.75 | 60.2 | 35.5 | 119 |
| 60. | 11-Cyclohexylheneicosane $C_{10}—\underset{\displaystyle \text{C}_6\text{H}_{11}}{\overset{\displaystyle |}{C}}—C_{10}$ | $C_{27}H_{54}$ | 36.10 | 17.53 | 8.73 | 3.75 | 86.5 | 38.7 | 116 |
| 9. | 11-Phenylheneicosane $C_{10}—\underset{\displaystyle C_6H_5}{\overset{\displaystyle |}{C}}—C_{10}$ | $C_{27}H_{48}$ | 30.96 | 15.30 | 7.78 | 3.44 | 78.4 | 37.0 | 112 |
| 52. | 11-Phenyl-10-heneicosene $C_9—C=C—C_{10}$ | $C_{27}H_{46}$ | 24.09 | 12.51 | 6.63 | 3.06 | 67.8 | 36.5 | 115 |
| 10. | 9-p-Tolyloctadecane $C_8—\underset{\displaystyle C_6H_4CH_3}{\overset{\displaystyle |}{C}}—C_9$ | $C_{25}H_{44}$ | 30.67 | 14.75 | 7.31 | 3.15 | 76.3 | 36.8 | 75 |
| 51. | 7-*n*Hexyleicosane $C_6—\underset{\displaystyle C_6}{\overset{\displaystyle |}{C}}—C_{13}$ | $C_{26}H_{54}$ | 19.62 | 10.69 | 5.89 | 2.86 | 61.2 | 35.8 | 131 |
| 11. | 1,1-Dicyclohexyltetradecane $[C_6H_{11}]_2C—C_{12}$ | $C_{26}H_{50}$ | Solid | 36.41 | 14.89 | 5.31 | 169.6 | 43.6 | 80 |
| 12. | 1,1-Diphenyltetradecane $[C_6H_5]_2C—C_{12}$ | $C_{26}H_{38}$ | 41.30 | 18.59 | 8.87 | 3.72 | 91.6 | 38.6 | 92 |
| 13. | 1,1-Diphenyl-1-tetradecene $[C_6H_5]_2C=C—C_{12}$ | $C_{26}H_{36}$ | 41.65 | 19.34 | 9.01 | 3.71 | 94.7 | 38.5 | 77 |
| 25. | 9-*n*Octylheptadecane $C_8—\underset{\displaystyle C_8}{\overset{\displaystyle |}{C}}—C_8$ | $C_{25}H_{52}$ | 16.03 | 8.93 | 5.04 | 2.49 | 55.2 | 34.6 | 116 |
| 26. | 9-*n*Octyl-8-heptadecene $C_7—C=\underset{\displaystyle C_8}{\overset{\displaystyle |}{C}}—C_8$ | $C_{25}H_{50}$ | 13.21 | 7.65 | 4.50 | 2.30 | 50.8 | 33.9 | 126 |
| 19. | 1-Cyclohexyl-3-(2-cyclohexylethyl)-hendecane $[C_6H_{11}—C_2]C—C_8$ | $C_{25}H_{48}$ | 84.38 | 33.49 | 13.94 | 4.98 | 156.4 | 42.5 | 70 |

**TABLE 1—Continued**

| Density (Grams Per Milliliter) | | | | Gravity (Deg API) | Melting Point (Deg C) | Boiling Point | | Heat of Vaporization (Calories Per Gram) | Refractive Index ($n^tD$) | | | Molecular Refraction | | Specific Refraction | Dispersion (20 Deg C) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| At 68 Deg F | At 100 Deg F | At 140 Deg F | At 210 Deg F | | | At 0.5-Mm Pressure (Deg C) | At 1.0-Mm Pressure (Deg C) | | At 20.0 Deg C | At 30.0 Deg C | At 40.0 Deg C | Experimental | Calculated | | Mean | Specific |
| 0.8046 | 0.7932 | 0.7787 | 0.7535 | 43.6 | 0.0 | 180 | 194 | 62.5 | 1.4500 | 1.4461 | 1.4423 | 122.2 | 122.3 | 333.9 $\times 10^{-3}$ | 0.00728 | 91 $\times 10^{-4}$ |
| 0.8041 | 0.7928 | 0.7782 | 0.7527 | 43.7 | 1.3 | 179 | 193 | 59.0 | 1.4498 | 1.4460 | 1.4423 | 122.3 | 122.3 | 334.2 | 0.00728 | 91 |
| 0.8040 | 0.7926 | 0.7782 | 0.7522 | 43.7 | 3.2 | 180 | 194 | 62.5 | 1.4499 | 1.4460 | 1.4423 | 122.3 | 122.3 | 334.2 | 0.00728 | 91 |
| 0.8057 | 0.7944 | 0.7794 | 0.7545 | 43.3 | 20.8 | 183 | 195 | 61.7 | 1.4503 | 1.4466 | 1.4428 | 122.1 | 122.3 | 333.8 | 0.00730 | 91 |
| 0.8078 | 0.7967 | 0.7818 | 0.7569 | 42.9 | 19.3 | 196 | 209 | 60.6 | 1.4517 | 1.4478 | 1.4441 | 131.5 | 131.5 | 333.7 | 0.00750 | 93 |
| 0.8112 | 0.7997 | 0.7853 | 0.7607 | 42.1 | 8.6 | 209 | 222 | 58.3 | 1.4537 | 1.4500 | 1.4461 | 140.8 | 140.7 | 335.0 | 0.00737 | 91 |
| 0.8127 | 0.8015 | 0.7874 | 0.7628 | 42.0 | 1.0 | 222 | 235 | 57.1 | 1.4543 | 1.4517 | 1.4469 | 150.0 | 150.0 | 333.5 | 0.00744 | 92 |
| 0.8115 | 0.8003 | 0.7860 | 0.7615 | 42.1 | 8.7 | 215 | 229 | 55.6 | 1.4540 | 1.4501 | 1.4462 | 145.5 | 145.4 | 333.7 | 0.00744 | 92 |
| 0.8697 | 0.8583 | 0.8443 | 0.8201 | 30.6 | Glass —40 deg C | 222 | 235 | 58.7 | 1.4778 | 1.4742 | 1.4707 | 140.6 | 141.0 | 325.5 | 0.00787 | 91 |
| 0.8038 | 0.7922 | 0.7775 | 0.7525 | 43.8 | — 9.1 | 178 | 192 | 62.1 | 1.4497 | 1.4459 | 1.4419 | 122.3 | 122.3 | 334.2 | 0.00739 | 92 |
| 0.8092 | 0.7979 | 0.7835 | 0.7587 | 42.6 | Glass —40 deg C | 175 | 188 | 60.6 | 1.4517 | 1.4480 | 1.4442 | 121.9 | 122.3 | 333.1 | 0.00726 | 90 |
| 0.8373 | 0.8259 | 0.8119 | 0.7874 | 36.8 | — 7.2 | 197 | 209 | 66.8 | 1.4639 | 1.4603 | 1.4567 | 124.5 | 124.7 | 329.4 | 0.00758 | 90 |
| 0.8531 | 0.8415 | 0.8270 | 0.8018 | 33.7 | 20.8 | 191 | 205 | 60.5 | 1.4788 | 1.4751 | 1.4713 | 123.6 | 123.3 | 332.2 | 0.00931 | 109 |
| 0.8636 | 0.8520 | 0.8376 | 0.8113 | 31.7 | Glass —40 deg C | 190 | 203 | 60.0 | 1.4922 | 1.4884 | 1.4845 | 124.4 | 122.8 | 336.1 | 0.01185 | 137 |
| 0.8549 | 0.8433 | 0.8283 | 0.8024 | 33.4 | Glass —40 deg C | 173 | 185 | 63.4 | 1.4811 | 1.4771 | 1.4734 | 117.0 | 114.0 | 337.2 | 0.0115 | 135 |
| 0.8040 | 0.7923 | 0.7780 | 0.7528 | 43.7 | 10.2 | 181 | 194 | 62.7 | 1.4497 | 1.4459 | 1.4421 | 122.3 | 123.3 | 334.2 | 0.00734 | 91 |
| Solid | 0.8620 | 0.8479 | 0.8240 | 29.9 | 37.6 | 193 | 206 | 64.7 | Solid | | | Solid | | | | |
| 0.9186 | 0.9068 | 0.8916 | 0.8659 | 21.9 | 17.9 | 194 | 207 | 66.7 | 1.5202 | 1.5162 | 1.5123 | 115.9 | 115.1 | 331.1 | 0.0134 | 146 |
| 0.9267 | 0.9143 | 0.8986 | 0.8725 | 20.6 | 16.3 | 192 | 205 | 67.0 | 1.5363 | 1.5322 | 1.5280 | 117.1 | 114.6 | 336.5 | 0.0165 | 178 |
| 0.8017 | 0.7903 | 0.7758 | 0.7504 | 44.2 | —13.8 | 172 | 184 | 63.1 | 1.4487 | 1.4449 | 1.4412 | 117.7 | 117.7 | 334.4 | 0.0078 | 91 |
| 0.8084 | 0.7963 | 0.7816 | 0.7563 | 42.8 | Glass —40 deg C | 168 | 181 | 64.1 | 1.4554 | 1.4516 | 1.4477 | 117.6 | 117.2 | 335.9 | 0.00966 | 120 |
| 0.8657 | 0.8546 | 0.8403 | 0.8156 | 31.3 | Glass —40 deg C | 182 | 195 | 65.6 | 1.4756 | 1.4719 | 1.4683 | 113.4 | 113.3 | 325.5 | 0.00805 | 93 |

been made in this work. Whenever possible, standard methods are being employed. The following list of properties represents those completed to date and the methods used to determine them:

1. The *kinematic viscosity* at 68, 100, 140, and 210° F was determined using the Cannon and Fenske type viscosimeter. This is ASTM D445-39T Method B. The Saybolt values were calculated using the standard ASTM Method D446-39.

2. The *kinematic viscosity* indices were calculated by the Dean and Davis tables, ASTM D567-40T.

3. The *densities* were measured at 68, 100, 140, and 210° F, using pycnometers holding about 5 ml. The values are correct to 0.0002 grams per milliliter. The gravity, in deg API, was calculated from extrapolated data.

4. The *melting points* were obtained very accurately from the melting curves used in establishing the purity. A description of the apparatus and method will be published separately.

5. *Boiling points* were taken from vapor-pressure curves. These were obtained over the range 0.5 mm to 5.0 mm through the courtesy of the Petroleum Refining Laboratory of this college. A special apparatus was used. [6]

6. The *heat of vaporization* was calculated for each compound by the use of the Clapeyron equation. The calculations were based on vapor-pressure data for the range 0.5 mm to 5.0 mm.

7. The *refractive indices* were measured at 20, 30, and 40° C, using a Valentine "Universal" Abbe-type refractometer. The results are correct to 0.0001 units.

8. The *specific refraction* was calculated for the compounds at 20° C by use of the Lorentz-Lorenz equation:

$$r=\frac{(n^2-1)}{(n^2+2)}\cdot\frac{1}{d}$$

9. Dispersion data were obtained from the drum readings of the refractometer at 20° C. From this, it was possible to obtain the *mean* and *specific dispersion* to 2 percent.

### Influence of Structure on Physical Properties

Until generalization can be drawn, this type of work has little fundamental value. However, comparison based on too few compounds may lead to erroneous concepts and, therefore, we shall limit this discussion to those classes that have been studied in detail. As the project continues and more compounds are prepared, additional generalizations will be possible.

After a critical survey of the literature, several groups of hydrocarbons were chosen for study. Of these the *iso*paraffins offered the greatest possibility, and have been studied in detail. From the *iso*paraffins the work is progressing to the naphthenes, aromatics, and mixed types. For the purpose of making the generalizations clearer, the types and series of hydrocarbons are grouped together.

### Position of Branch on Carbon Chain in an *Iso*paraffin

Most of the earlier workers had assumed that the position or length of a branch on a carbon chain of an *iso*paraffin of high molecular weight had little or no influence on the properties as long as the molecular weight was constant. A thorough investigation of this subject

**TABLE 2**

**$C_{26}H_{54}$ *Iso*paraffins**

| PSC No. | Name of Structure | Melting Point (Deg C) | Viscosity at 100 Deg F (Centistokes) | Kinematic Viscosity Index | Boiling Point at 1.0 Mm Pressure (Deg C) | $n^{20}D$ | $d_4^{20}$ | $M_D$ * |
|---|---|---|---|---|---|---|---|---|
| 1. | 11-*n*Butyldocosane<br>$C_{10}—C(C_4)—C_{11}$ | 0.0 | 10.41 | 124 | 193 | 1.4500 | 0.8046 | 122.2 |
| 2. | 9-*n*Butyldocosane<br>$C_8—C(C_4)—C_{13}$ | 1.3 | 10.61 | 128 | 193 | 1.4498 | 0.8041 | 122.3 |
| 3. | 7-*n*Butyldocosane<br>$C_6—C(C_4)—C_{15}$ | 3.2 | 11.10 | 131 | 194 | 1.4499 | 0.8040 | 122.3 |
| 4. | 5-*n*Butyldocosane<br>$C_4—C(C_4)—C_{17}$ | 20.8 | 11.48 | 138 | 195 | 1.4503 | 0.8057 | 122.1 |
| 51. | 7-*n*Hexyleicosane<br>$C_6—C(C_6)—C_{13}$ | 10.2 | 10.69 | 131 | 194 | 1.4497 | 0.8040 | 122.3 |
| 27. | 11-*n*Amylheneicosane<br>$C_{10}—C(C_5)—C_{10}$ | −9.1 | 10.08 | 125 | 192 | 1.4497 | 0.8038 | 122.4 |
| 53. | 11-(3-Pentyl)-heneicosane<br>$C_{10}—C(C_5H_{11})—C_{10}$ | Glass −40 deg C | 10.39 | 119 | 188 | 1.4513 | 0.8092 | 121.9 |

* $M_D$ (molecular refraction) calculated for $C_{26}H_{54}$ 122.3.

has shown that this generalization is approximately true only for properties such as index or refraction, density, and boiling point. It fails completely for melting point and viscosity.

The most obvious effect is that of structure on melting point. The factors which influence the melting point include symmetry, the existence of stereoisomerism, and the approach to a long straight chain. These have been recognized for some time in numerous classes of organic compounds.

Up to the present time the relation of viscosity to structure in *iso*paraffins has not been studied in detail. Hugel [2] incorrectly assumed that branching had little or no influence on viscosity. The error of this assumption is shown by a difference of 14 percent in the viscosity of compounds PSC 4 and PSC 27. From tendencies shown here, it should be possible to prepare compounds in which the variation is even greater.

As the substituent chain is moved nearer the center of the molecule, the viscosity decreases rapidly. This may be observed clearly for PSC compounds 1 to 4 and the other compounds in Table 2. Increasing of length of the side chain and decreasing that of the main chain tends to lower the viscosity as shown by the pairs of PSC compounds 1,27 and 4,51. Clustering of the side chain as in PSC 53, in comparison to PSC 27, increases the viscosity. This resembles the effect found in naphthenes of corresponding molecular weight. Compounds having several branches are in preparation, and these should clarify the entire question of the influence of structure on viscosity in *iso*paraffins.

The changes in kinematic viscosity index follow very closely the generalization made for the viscosity except for one compound, PSC 53. This compound, due to its clustered branching, is approaching the cyclopentyl compound. Such a naphthene compound undoubtedly would have a lower viscosity index.

The variation of the boiling points is the same as that found in the hydrocarbons of lower molecular weight. The differences produced by the change in molecular structure are somewhat less marked in the high-molecular-weight range. Although the variations are only slight, they are outside the limits of error. The important factor seems to be the symmetry of the molecule.

The other properties, such as refractive index and density, are not influenced to such an extent by structure. As the molecule becomes more compact, the density increases—and this tends to increase the refractive index. The molecular refraction relates these two properties. As may be seen from Table 2, this is practically constant for all of the variations in structure.

### Increases of Molecular Weight in *Iso*paraffins

In all classes of organic compounds an increase in molecular weight has a pronounced effect on the physical properties. This has been found true with the *iso*paraffins. This influence is summarized in Table 3.

In all the properties listed in Table 3, other than the melting point, there are somewhat regular increases with the molecular weight. When these compounds that vary in molecular weight are compared, many isomers are possible. Comparison of the compounds listed in Table 3 with those in Table 2 shows that the structural influences in *iso*paraffins are small compared with those due to changes in molecular weight.

Figures 5 and 6 show the regularity of the effect on the properties by increases in molecular weight. PSC compound 25, 9-*n*octylheptadecane, is out of line in its properties. This is due to the high degree of symmetry when compared to 5-*n*butyldocosane (PSC 4). Although PSC compound 8 is just as symmetrical as PSC 25, it does not differ so much from PSC 6 and PSC 7.

### Comparison of *Iso*paraffin, Naphthene, and Aromatic

The influence of structural differences of this kind has been recognized by most of the recent workers in

**TABLE 3**

**$C_{25}H_{52}$—$C_{32}H_{66}$ *Iso*paraffins**

| PSC No. | Name of Structure | Melting Point (Deg C) | Viscosity at 100 Deg F (Centistokes) | Kinematic Viscosity Index | Boiling Point at 1.0 Mm Pressure (Deg C) | $n^{20}D$ | $d_4^{20}$ | $M_D$ |
|---|---|---|---|---|---|---|---|---|
| 25. | 9-*n*Octylheptadecane ..... $C_8—C(C_8)—C_8$ $C_{25}H_{52}$ | −13.8 | 8.93 | 116 | 184 | 1.4490 | 0.8017 | 117.7 |
| 4. | 5-*n*Butyldocosane ..... $C_4—C(C_4)—C_{17}$ $C_{26}H_{54}$ | 20.8 | 11.48 | 138 | 195 | 1.4503 | 0.8057 | 122.1 |
| 5. | 7-*n*Hexyldocosane ..... $C_6—C(C_6)—C_{15}$ $C_{28}H_{58}$ | 19.3 | 13.10 | 144 | 209 | 1.4517 | 0.8078 | 131.5 |
| 6. | 9-*n*Octyldocosane ..... $C_8—C(C_8)—C_{13}$ $C_{30}H_{62}$ | 8.6 | 14.43 | 148 | 222 | 1.4537 | 0.8112 | 140.8 |
| 8. | 11-*n*Decylheneicosane ..... $C_{10}—C(C_{10})—C_{10}$ $C_{31}H_{64}$ | 8.7 | 15.12 | 149 | 229 | 1.4540 | 0.8115 | 145.5 |
| 7. | 11-*n*Decyldocosane ..... $C_{10}—C(C_{10})—C_{11}$ $C_{32}H_{66}$ | 1.0 | 16.53 | 155 | 235 | 1.4543 | 0.8127 | 150.0 |

petroleum chemistry. With the compounds studied by us, these changes in properties due to variations of hydrocarbon type are startling in comparison to variations in the *iso*paraffins due to changes in structure or

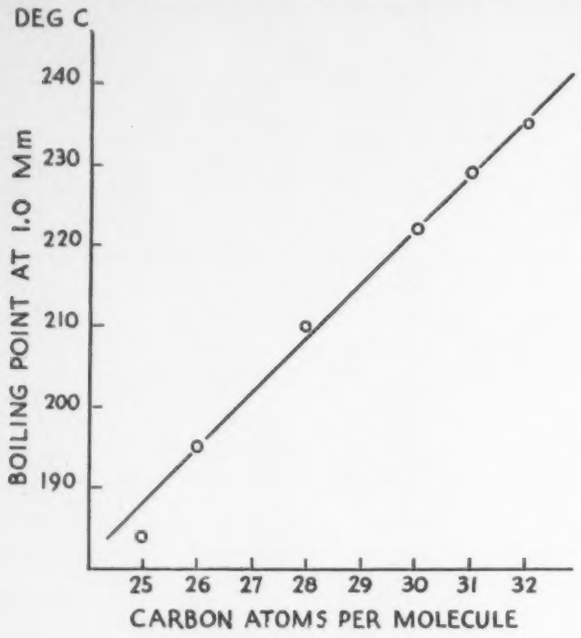



**FIGURE 5**
**Change of Boiling Point with Molecular Weight in *Iso*paraffins.**

in molecular weight. Several series of hydrocarbons have been prepared for the purpose of studying these factors. They are summarized in Tables 4, 5, and 6.

The melting points of these compounds vary widely with changes in type. Generalizations apparent for the series in Table 4 do not hold for other series (see Table 5). Therefore, real generalization must wait until more data are available.

The influence of changes in structural type on viscosity and viscosity index are of the greatest importance. The substitution of two benzene rings (PSC 12) for the two *n*hexyl chains in 7-*n*hexyleicosane (PSC 51) almost doubles the viscosity. Hydrogenation of these rings to the naphthene (PSC 11) almost quadruples it in comparison to the straight chain. In a similar manner there are very definite changes in the viscosity index. These generalities hold qualitatively for the compounds in Tables 5 and 6. On the basis of the present regularities, more exact relationships should be obtainable when more compounds have been completed.

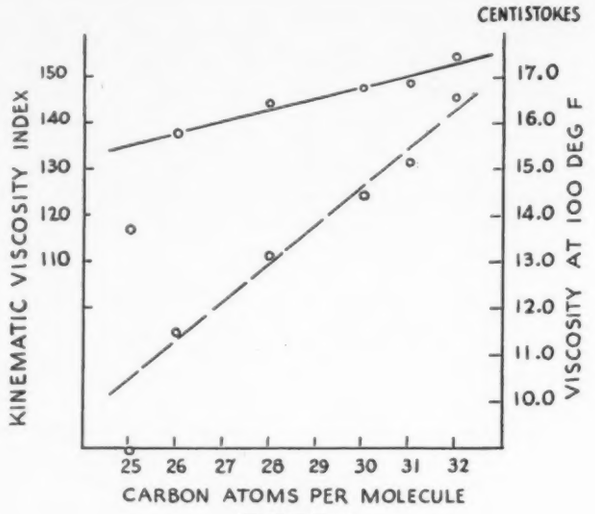



**FIGURE 6**
**Change of Kinematic Viscosity with Molecular Weight in *Iso*paraffins.**

The boiling points of the compounds studied indicate that the substitution of a naphthene or aromatic ring in place of a straight chain of the same carbon content

**TABLE 4**
**Various Types of $C_{26}$ Hydrocarbons**

| PSC No. | Name of Structure | Melting Point (Deg C) | Viscosity at 100 Deg F (Centistokes) | Kinematic Viscosity Index | Boiling Point at 1.0 Mm Pressure (Deg C) | $n^{20}D$ | $d_4^{20}$ |
|---|---|---|---|---|---|---|---|
| 51. | 7-*n*Hexyleicosane ..... $C_6—C(—C_{13})(—C_6)$ | 10.2 | 10.69 | 131 | 194 | 1.4497 | 0.8040 |
| 13. | 1,1-Diphenyl-1-tetradecene ..... $[C_6H_5]_2C=C—C_{12}$ | 16.3 | 19.34 | 77 | 205 | 1.5363 | 0.9267 |
| 12. | 1,1-Diphenyl-tetradecane ..... $[C_6H_5]_2C—C_{13}$ | 17.9 | 18.59 | 92 | 207 | 1.5200 | 0.9186 |
| 11. | 1,1-Dicyclohexyl-tetradecane .... $[C_6H_{11}]_2C—C_{13}$ | 37.6 | 36.41 | 80 | 206 | 1.4795 * | 0.8620 at 100 deg F |

* Super-cooled sample.

**TABLE 5**

**Various Types of Hydrocarbons**

| PSC No. | Name of Structure | Melting Point (Deg C) | Viscosity at 100 Deg F (Centistokes) | Kinematic Viscosity Index | Boiling Point at 1.0 Mm Pressure (Deg C) | $n^{20}D$ | $d_4^{20}$ |
|---|---|---|---|---|---|---|---|
| 9. | 11-Phenylheneicosane<br>$C_{10}—C(—C_{10})$<br> | 20.8 | 15.30 | 113 | 205 | 1.4788 | 0.8531 |
| 60. | 11-Cyclohexylheneicosane<br>$C_{10}—C(—C_{10})$<br> | −7.2 | 17.58 | 116 | 209 | 1.4640 | 0.8372 |
| 62. | 11-a-Decalinheneicosane<br>$C_{10}—C(—C_{10})$<br> | Glass −40 deg C | 45.67 | 95 | 235 | 1.4778 | 0.8697 |
| 8. | 11-n-Decylheneicosane<br>$C_{10}—C(—C_{10})(—C_{10})$ | 8.7 | 15.12 | 149 | 229 | 1.4557 | 0.8115 |

gives rise to a definite increase in the boiling point. However, hydrogenation of an aromatic ring to a naphthene has only a slight effect in comparison. This is illustrated by the compounds in Table 4, in particular. The effect is found also in the compounds in Tables 5 and 6.

The influences of structural differences on refractive index and density are shown in Tables 4, 5, and 6. As may be observed from the tables, these properties vary widely with the changes in structure. Molecular refraction is a function that relates density and index of refraction to values that may be calculated on the basis of empirically obtained data from other types of compounds. Table 7 is a tabulation of some of these molecular-refraction calculations. From a study of this table, it is evident that molecular refraction is very useful in the establishing of the structure of a compound, or in checking the purity.

## Molecular Refraction

Molecular refraction has been found a very useful check on the purity and identity of our compounds. The agreement of the experimental and the calculated molecular refractions is shown in Table 7.

The calculated value is obtained by assuming a structure for the compound and adding up the well-known

**TABLE 6**

**Various Types of $C_{25}$ Hydrocarbons**

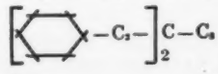
| PSC No. | Name of Structure | Melting Point (Deg C) | Viscosity at 100 Deg F (Centistokes) | Kinematic Viscosity Index | Boiling Point at 1.0 Mm Pressure (Deg C) | $n^{20}D$ | $d_4^{20}$ |
|---|---|---|---|---|---|---|---|
| 26. | 9-*n*Octyl-8-heptadecene<br>$C_7—C(=C(—C_8)—C_8)$ | Glass −40 deg C | 7.65 | 126 | 181 | 1.4554 | 0.8084 |
| 25. | 9-*n*Octylheptadecane<br>$C_8—C(—C_8)(—C_8)$ | −13.8 deg C | 8.93 | 116 | 184 | 1.4490 | 0.8017 |
| 19. | 1-Cyclohexyl-3-(2-cyclohexylethyl)-hendecane<br>  | Glass −40 deg C | 33.49 | 70 | 195 | 1.4756 | 0.8657 |

**TABLE 7**
**Molecular Refractions of Various Types of Hydrocarbons**

| PSC No. | NAME | Experimental | Calculated |
|---|---|---|---|
| 51. | 7-*n*Hexyleicosane | 122.3 | 122.3 |
| 12. | 1,1-Diphenyltetradecane | 115.9 | 115.1 |
| 9. | 11-Phenylheneicosane | 123.6 | 123.3 |
| 60. | 11-Cyclohexylheneicosane | 124.5 | 124.7 |
| 8. | 11*n*-Decylheneicosane | 145.5 | 145.4 |
| 62. | 11-*n*Decalinheneicosane | 140.6 | 141.0 |
| 25. | 9-*n*Octylheptadecane | 117.7 | 117.7 |
| 19. | 1-Cyclohexyl-3-(2-cyclohexylethyl-hendecane | 113.4 | 113.3 |

atomic values. The experimental is obtained from the Lorentz-Lorenz equation. From the equation:

$$M_D=\frac{(n^2-1)M}{(n^2+2)d}$$

*Where:*

$n=n^{20}D$

$d=d_4^{20}$

M=molecular weight.

It is obvious that any variation in the index refraction or the density would cause large differences in the experimental value of the molecular refraction.

This agreement constitutes one proof of structure, and indicates the purity of the compound. It does not eliminate the possibility of the substance being a mixture of isomers or some mixtures of various types of hydrocarbons, but it does remove all question of the substance being an alcohol, ketone, or an ester. In these compounds the relationship between index of refraction and density is such that there can be little chance of confusion. The presence of one of these oxygenated impurities materially influences the molecular refractions. Thus any large difference in the experimental and theoretical values indicates an impure compound. The only case when this generalization does not hold is in compounds having conjugated double bonds. With these compounds, exaltations are produced that cannot be predicted exactly.

## Molecular Volume

Recently Kurtz and Lipkin[7] have listed a series of atomic values to be used in calculating the theoretical molecular volume of saturated hydrocarbons. The experimental molecular volume depends upon an exact determination of the density at 20° C. The molecular weight divided by this gives the molecular volume in milliliters per mole. Table 8 is a list of several of these values.

**TABLE 8**
**Molecular Volumes**

| PSC No. | COMPOUND | Experimental PSC | Calculated Kurtz | Percent Deviation |
|---|---|---|---|---|
| 19. | 1-Cyclohexyl-3-(2-cyclohexylethyl)-hendecane | 402.0 | 400.6 | 0.35 |
| 60. | 11-Cyclohexylheneicosane | 451.4 | 451.0 | 0.09 |
| 4. | 5-*n*Butyldocosane | 454.3 | 454.5 | 0.04 |
| 51. | 7-*n*Hexyleicosane | 455.2 | 454.5 | 0.15 |
| 5. | 7-*n*Hexyldocosane | 487.7 | 487.0 | 0.14 |
| 6. | 9-*n*Octyldocosane | 520.2 | 519.6 | 0.11 |
| 7. | 11-*n*Decyldocosane | 552.2 | 553.7 | 0.31 |
| 62. | 11-a-Decalinheneicosane | 497.3 | 498.7 | 0.30 |


## Acknowledgment

The authors wish to express their sincere gratitude to the American Petroleum Institute for the funds that made Project 42 possible; and to our director, Dean F. C. Whitmore, for his guidance throughout the progress of this work. Special acknowledgment should go to our advisory committee, Doctors L. C. Beard, L. A. Mikeska, and C. R. Wagner, for their unlimited interest, encouragement, and helpful criticisms.

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# The Testing of Heavy Duty Motor Oils

HARRY C. MOUGEY, General Motors Corporation
and
JOSEPH A. MOLLER, The Pure Oil Company

DURING the past several years the oxidation and corrosive characteristics of lubricating oils have been studied by means of various laboratory devices and tests. However, since correlation with field results was not always obtained, these tests, whether considered individually or collectively, left much to be desired. While this was true insofar as the service conditions for engines then in the field were concerned, newer types of engines began to appear which, because of the additional severity of operating conditions, could not be correlated with the then used laboratory tests.

In discussing field results, it should be remembered that these results were obtained with certain oils under a variety of operating conditions in actual service. Therefore these oils, of known performance, constituted ideal test specimens for, first, judging the merits of a test device as to its ability to predict, from laboratory test results, the performance of these and other oils in service. Secondly, these same oils, once the laboratory test method is established, would lend themselves to a still further, and perhaps even more essential service, in that test results obtained from them would form a pattern upon, or against, which the field performance of an unknown oil might be evaluated from laboratory tests.

In the meantime, one engine builder who had had the problem of lubricating oil deposition to contend with, perhaps a little earlier than some of the other engine designers, had developed a series of engine tests to define for him, the petroleum supplier, and the user, the ability of an oil to give satisfactory service. These tests were somewhat cumbersome, but as long as only one manufacturer required them, no one suffered very much. However, shortly thereafter, another engine manufacturer began to run into some troubles of his own in the field. For him to define the ability of an oil to give satisfactory performance in service, it was necessary to set up another type of test, using another engine and a different procedure.

About that time, yet another make of engine began having difficulty with the ordinary run of the mine lubricating oils, and again it was necessary to have a test set up which would define a lubricant for satisfactory service, using still another engine and a different procedure.

Obviously, it would be but a question of time before other engine manufacturers would design newer and different types of engines requiring yet more test programs, and perhaps resulting in yet further specialization of lubricating oils for each type of engine. Such a series of test programs, which would, perforce, have to be conducted by each engine builder for all oils and by each petroleum refiner for all engines, would be prohibitive from the point of view of the expense and the time involved.

Probably the one reason why all of this was taking place was because the manufacturer of lubricating oils lacked the means of refining, or describing, in any interpretable or understandable language for the engine designer, the user, or himself, the physical limitations which should be imposed upon the designer for his design with reference to the use of the oil itself.

At about this stage of events, two sub-committees, of Sub-Division B of the Lubricants Division of the Society of Automotive Engineers, had been meeting individually and collectively in an effort to describe both by definition and specification, heavy duty conditions. The thought was, of course, that, if a satisfactory description of heavy duty conditions could be evolved, this definition, used as a specification, could then be applied to oils satisfactorily meeting these conditions. Further, that since the conditions were probably more susceptible of definition and description in terms with which both the engine designer and petroleum refiner were already familiar, such a definition for heavy duty motor oils could more easily be understood and applied by both industries than could a description of the oil alone in terms of some yet to be developed nomenclature.

Fortunately, for all concerned, sufficient work had already been done so that most of the desirable, and the undesirable, properties of heavy duty motor oils were at least generally understood. The only problem was to define, describe, and compare them by means of some common yardstick.

It was generally conceded that the Caterpillar series of tests, as then outlined, quite adequately defined and described the detergent and dispersive properties of the oil; that the General Motors Series 71, five hundred hour test, defined and described to some degree the combination of both the detergent and dispersive properties, together with the oxidation characteristics of the oil; and, that the Chevrolet Varnish procedure placed the greatest emphasis on the oxidation characteristics of the oil.

In other words, the Caterpillar series tested primarily the detergent and dispersive characteristics of the oil, while the Chevrolet Varnish procedure tested the oxidation characteristics.

Probably the most important remaining characteristic, from the point of view of heavy duty operating conditions, which had to be considered, was the corrosive characteristic of the oil. Both the Caterpillar series and the General Motors Series 71 test had

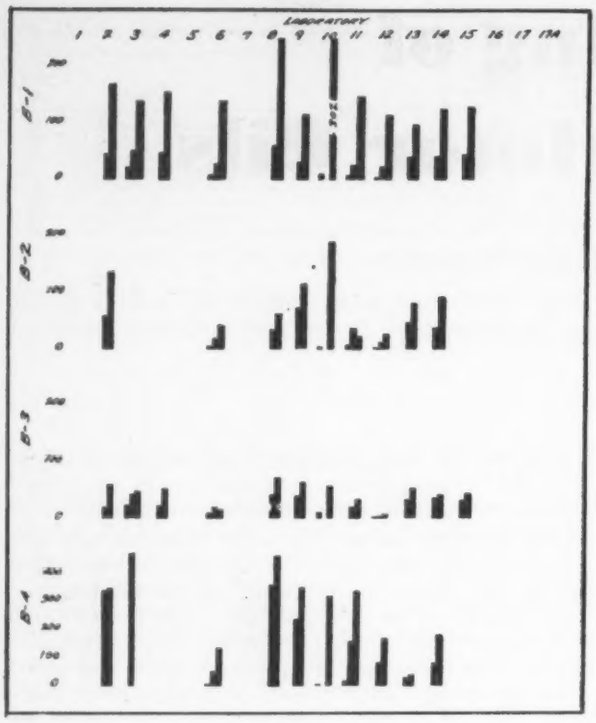


**FIGURE 1**
**Naphtha Insoluble Milligrams/100 G.M.—36 Hours**

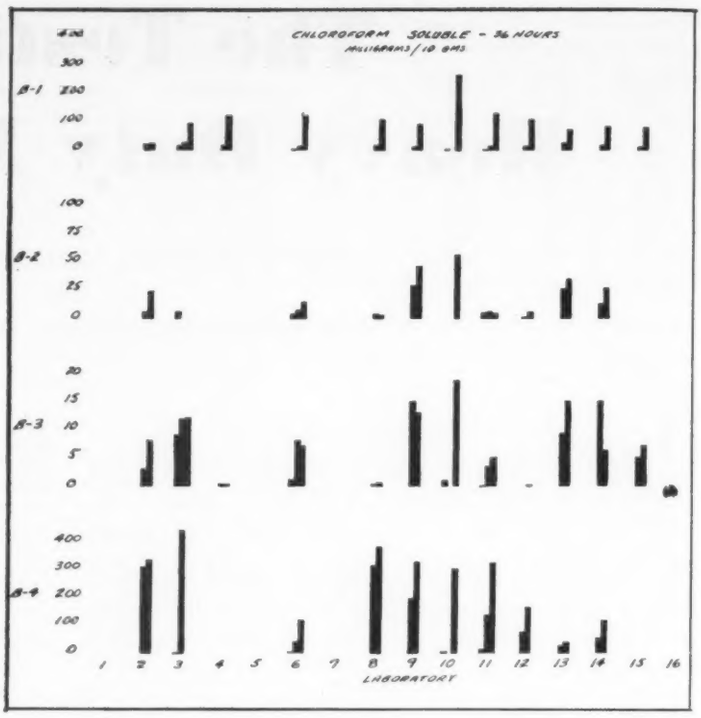


**FIGURE 2**

provisions for the study of corrosion already incorporated in them.

The Chevrolet test was probably the most desirable test to be used for several reasons. Many laboratories were already set up to run these tests. The engines were relatively inexpensive, and, since the engines were production models, replacement parts were relatively inexpensive and easy to obtain. However, all laboratories were not obtaining comparable results. On the one hand, it was obvious that a considerable amount of work had to be done so that discrepancies in results obtained by different laboratories could be ironed out before the test could be considered as a common yardstick for the definition of the oxidation characteristics of oils under heavy duty conditions. On the other hand, if this type of correlation between laboratories could be accomplished for one set of conditions, it could then be done for any set of operating conditions within limits yet to be determined. From many points of view, a complete study of the Chevrolet Varnish test and the procedure appeared as the first step towards a readily understandable, and hence usable, type of motor oil specification for both the engine designer and the petroleum refiner.

Accordingly, the two S.A.E. Sub-Committees met on January 9, 1941, and passed the following recommendations:

"1. In principle the Committee recognizes the use of engine tests as a criterion for acceptable performance of oil.

"2. The Committee tentatively accepts the General Motors '71' and Caterpillar under present recommended procedures for such use with the definite recommendations:

"(a) that the work on the substituting of the Chevrolet engine for the Model 71 Diesel, under its present or modified procedure be expedited by all concerned, and that

"(b) the work toward the shortening of the present Caterpillar procedure by expedited."

In accordance with this recommendation, the two Committees held a meeting on January 14, 1941, for the purpose of discussing, altering, and amending the Chevrolet Varnish Test Procedure towards the end that, for a definite series of reference oils, selected because of their field service, definite and reproducible results could be obtained in, and between, participating laboratories.

There is not much to be gained, at this time, in discussing in detail the first test procedure or the results obtained on the three reference oils, except to state that the results were highly encouraging. Early in the cooperative work it became apparent that all of the factors influencing the results in this first test procedure were not adequately controlled. Accordingly, some rather intensive work was done by a few laboratories in an effort, first, to account for and explain the magnitude of the influence of these factors alone, and, second, their effect in combination with other test variables.

The net result of the first series of runs, using the so-called 66⅔ Hour Procedure, together with the additional work of a few of the laboratories, resulted in the so-called 36-Hour Chevrolet Varnish Procedure. The first series of oils which were used as reference oils did not contain an oil of the commonly called "varnishing" type. Consequently, a fourth reference oil was added to the first three, resulting in a rather complete series of reference oils both from the point of view of standardizing an engine and its procedure, as well as giving a good reference oil pattern against which to evaluate an unknown oil or oils.

Rather than discuss the results of the first 36 hour procedure on a numerical basis, a series of bar graphs have been prepared for quick scanning.

Figure 1 shows the comparative results obtained in the 36-hour test on the four reference oils within the same laboratory for naphtha insoluble results by

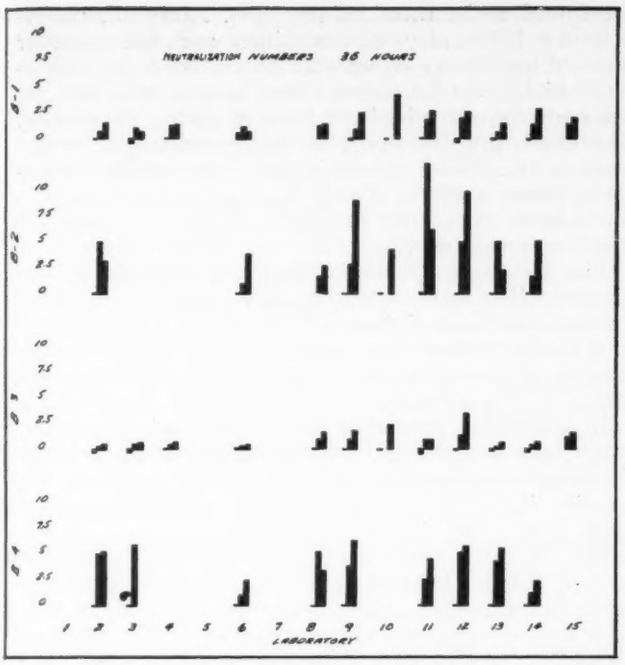


FIGURE 3

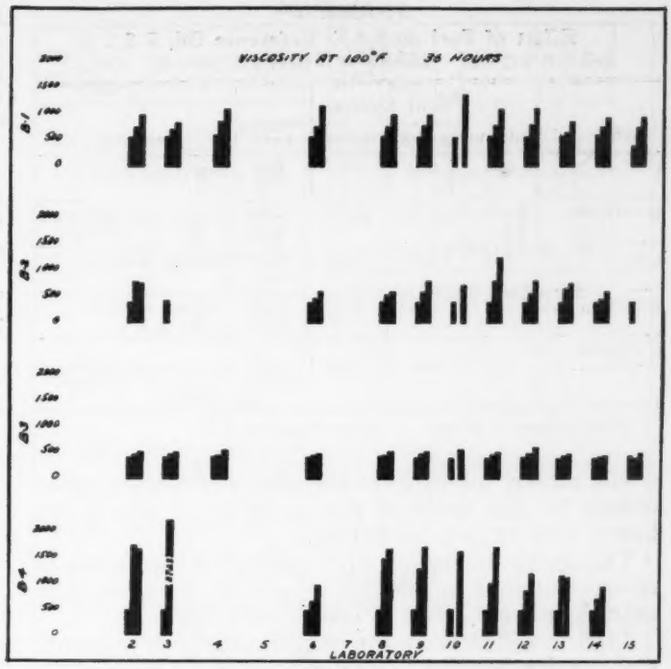


FIGURE 4

reading vertically, and for each reference oil between laboratories by reading horizontally.

Figure 2 shows the chloroform soluble results. When the fact that the oil is oxidized in engines operated in different laboratories and then sampled and chemically tested is recalled, these results really do check surprisingly well.

Figure 3 shows the neutralization number results obtained on the oil — the new, the sixteen hour, and the thirty-six, or drain, sample. Note the order of acid number—oils B-3, B-1, B-4, and B-2. This is in accord with field results.

The relative neutralization number results should be remembered so that when the corrosive results are shown, the fact that neutralization number is not always indicative of corrosion may be seen.

Figure 4 illustrates, in the same manner, the viscosity of the oil in three steps — the new oil, the sixteen hour sample and the final, or drained, sample. The fact that several laboratories cut their run before the 36 hour test period expired because of high acid number, or in one or two cases because of actual bearing failure due to corrosion, is shown by the lack of final data on the diagrams. However, the fact that results such as this can be obtained in different laboratories which are widely separated geographically

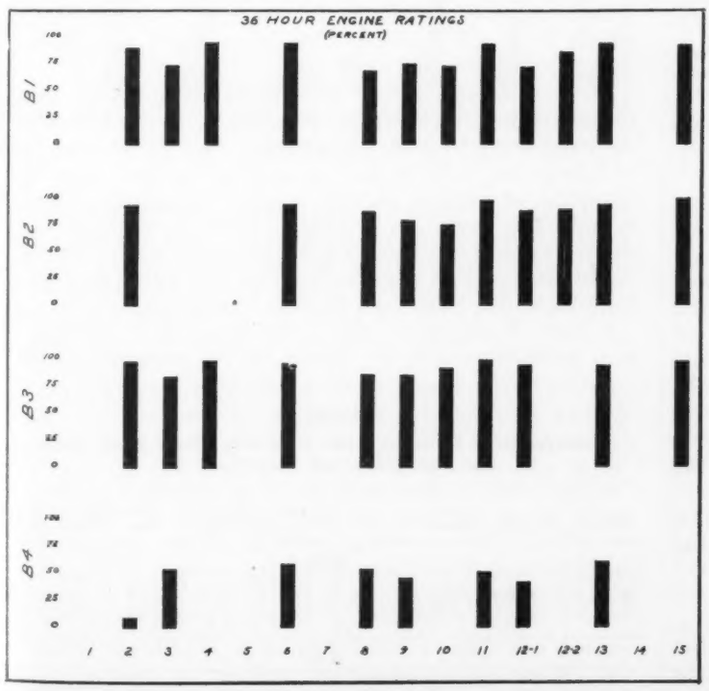


FIGURE 5

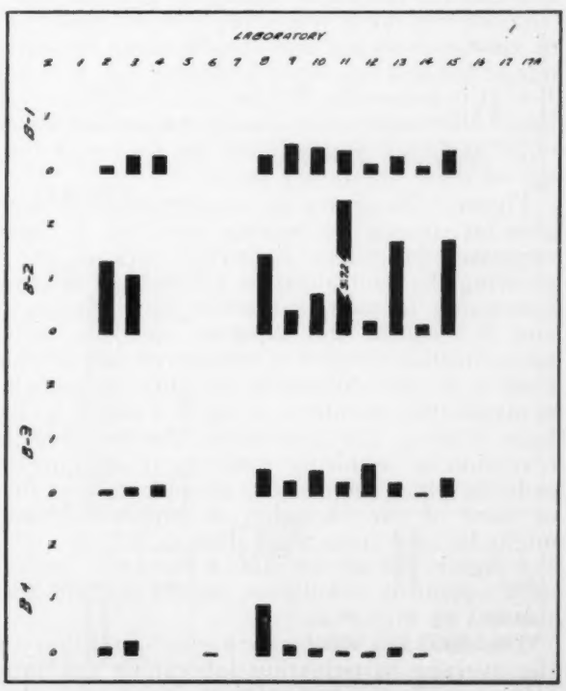


FIGURE 6
**Bearing Loss in Grams—Copper Lead Inserts 36 Hours**

**FIGURE 7**
**Effect of Fuel on S.A.E. Reference Oil, B-2 (36-Hour Tests)**

| FUEL | Sulphur | Neut. Number 16 Hrs. | Neut. Number 36 Hrs. | Bearing Loss | Remarks |
|---|---|---|---|---|---|
| Q..... | 0.06 | 5.02 | 3.62 | 1.49<br>1.13 | Severe oxidation. |
| Q+DXDS.... | 0.13 | 0.22 | 0.28* | 0.02*<br>0.03* | Engine fuel parts stuck up. No oxidation. |
| Q+$CS_2$..... | 0.48 | 2.29 | 4.08 | 0.44<br>1.53 | Medium oxidation. |
| Q+$CS_2$..... | 1.33 | 2.91† | .... | 0.08†<br>0.22* | Medium oxidation. |
| Q+DXDS +Oil..... | 0.09 | 0.46 | 1.16 | 0.03<br>0.04 | Test completed satisfactorily. No oxidation. |

* Test stopped at 22 hrs. † Test stopped at 16 hrs.

would clearly indicate the suitability of this test procedure for the study of the oxidation of oils under heavy duty engine conditions.

The above four slides give, generally, the chemical results obtained on the oils themselves as a result of only the second series of cooperative tests.

Figure 5 illustrates the engine rating, in percentage, obtained by the laboratories. Briefly, the scoring method used divides the rating into two portions — sludge and varnish. Each engine part is rated separately, and then the grand average computed from the individual ratings. Note that from the reported ratings, B-2 oil looks quite good. As stated before, many of these runs were stopped before the 36 hour period expired. However, it is true B-2 oil does leave the engine quite free of deposits, so from this point of view the rating is correct. On the other hand, experience has shown that if an oil of the B-2 type is used long enough in continuous heavy duty service, a coffee ground type of sludge generally develops.

It should be noted that, just as the oxidation of the oil was expressed as increased viscosity in an earlier figure, so are the results of the oxidation of the oil expressed in the engine ratings as given on this chart. The order of merit would be, from an oxidation point of view and taking into consideration the early cut-offs of the B-2 run, something like B-3, B-1, B-2, and B-4. It is interesting to note that field results, under heavy duty operating conditions, would check this order and even approximate the degree of the average of these laboratory tests.

Figure 6 illustrates the results obtained in the engine test insofar as bearing corrosion is concerned, expressed in grams. Referring back to the figure showing the neutralization numbers, it is extremely interesting to note that while the corrosion of B-3 and B-1 checks the expected corrosion when the neutralization number is considered, oils B-2 and B-4 show a decided difference. In other words, while the neutralization numbers of the B-2 and B-4 oils were both of about the same order, the resulting bearing corrosion is decidedly different. Consequently, the order in which the test oils are placed, from the point of view of the corrosion of copper-lead bearings, might be read from these data as B-3, B-1, B-4, and B-2. Again, the service data on these oils, under heavy duty operating conditions, would confirm these results.

The data, as a whole, are highly satisfactory in that the average participating laboratory has rated the reference oils, from the point of view of both oxidation and corrosion, in the same order as these oils are found to be rated in the field. After all, multi-cylinder laboratory test engines are but another piece of laboratory equipment much like a viscosimeter, which must be standardized with a standard, or reference, oil to obtain a known series of results. Therefore, the first stage of this work might be defined as the ability to obtain, in and between laboratories using a series of standard test oils, reproducible data in the order in which these same oils are rated in actual service.

The second stage would be the evaluating of unknown oils against the pattern obtained on the known, or standard, test oils.

A further check series, but of SAE 10 grade reference oil, is being run by the participating laboratories and, it is hoped, will be reported by January.

In analyzing the data just submitted, especially when two or three of the laboratories do not check the results generally obtained, it is necessary to determine just why they were out of line. It would appear that, while four laboratories were out of line, based on the general numerical averages obtained, two of these laboratories still rated the oils in the same order as did the majority of the laboratories.

A careful analysis of the results of the work of these laboratories indicates that there is a possibility of a fuel difference between some of the laboratories because it would appear that some fuels may contain, in themselves, natural or added inhibitors or catalysts.

With reference to the fuel itself, while there has been but little time to obtain data to clearly indicate limits of certain fuel ingredients, natural or otherwise, some work has been done which indicates that certain fuel ingredients may have a decided effect upon test engine results. Obviously, if a fuel contains an inhibitor to a greater or lesser extent, it will have but little effect on oils already inhibited. But in the case of oils which are not inhibited, such as B-2 and B-4, the effect would obviously be much more marked. Accordingly, some runs were used placing sulphur compounds in the fuel. It is interesting to note the marked inhibiting effect which was obtained using B-2 oil which, from the previous data, would be found to be a highly corrosive type of oil.

It is understood that the materials used in this series are not necessarily desirable in fuels, but that the runs serve to point out the fact that the inhibiting of lubricating oils in the sump of an engine may be obtained, at least in part, by inhibiting agents placed, or naturally found, in the fuel. These ingredients find their way into the sump by means of blow-by, which, in the case of this engine, is about one cubic foot per minute, under these test engine conditions.

Figure 7 illustrates the point that the neutralization number of B-2 oil, which would normally be in

**FIGURE 8**
**Comparative Runs by Lab. 14 Using Their Fuel and the Fuel Obtained from Lab. 13**

| FUEL | V/100 | Con. Carb. | Ash | Neut. No. | Naph. Insol. | Chl. Sol. | Bear. Loss Average |
|---|---|---|---|---|---|---|---|
| | | | B-2 | | | | |
| 14..... | 618 | 1.98 | .18 | 5.18 | 93.8 | 25.6 | .1665 |
| 13..... | 671 | 3.06 | .48 | 6.54 | 70.6 | 15.8 | 1.8417 |
| | | | B-4 | | | | |
| 14..... | 951 | 2.18 | .06 | 2.44 | 179.4 | 113.8 | .02225 |
| 13..... | 2151 | 3.77 | .13 | 9.48 | 554.6 | 331.0 | .2423 |

the neighborhood of 3.0 to 5.0, under these test conditions in 22 hours, has been held to 0.28 by means of .5% by volume of a sulphur compound placed in the fuel. The second and the third run indicate that, while some inhibiting effect might be obtained by means of another sulphur compound, the effect was not as great as was obtained with the material used in the first run. The fourth run, wherein mineral oil was used as a carrier for the sulphur compound, indicates quite clearly the fact that the neutralization number of even this highly corrosive oil can be maintained at a fairly low level by means of an inhibiting agent placed in the fuel. It should be pointed out that, since the only source of the inhibiting compound is from the blow-by gases, a definite period of time must elapse before the accumulative result of the blow-by gases will become sufficient to cause an inhibiting action of the sump oil, since per unit time but a very small amount of inhibiting material is made available to the sump oil.

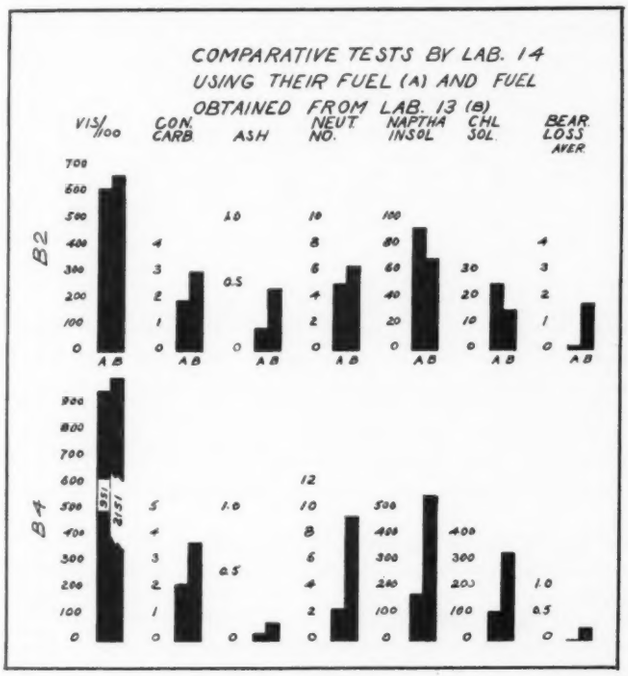


FIGURE 9

Further work was done in an effort to determine the extent of the influence of the fuel upon the tests as run by the participating laboratories themselves. Laboratory 14, while rating the oils in the proper order, did not agree with the numerical values obtained by the other laboratories, especially on oils B-2 and B-4.

Accordingly, laboratory 14 obtained from laboratory 13 the same type of fuel which laboratory 13 had used in making its runs. Laboratory 14 then repeated its runs on B-2 and B-4 oil using exactly the same engines and procedure as it had used in the cooperative runs. The numerical values obtained from these two runs are shown in Figure 8.

Figure 9 is a bar graph illustrating the difference between the two runs on each oil, drawn from the data shown in Figure 8.

From these data, it is quite obvious that the differences in both oil analysis and test engine results, as originally reported by laboratory 14, and the same results as laboratory 14 now reports them, using fuel

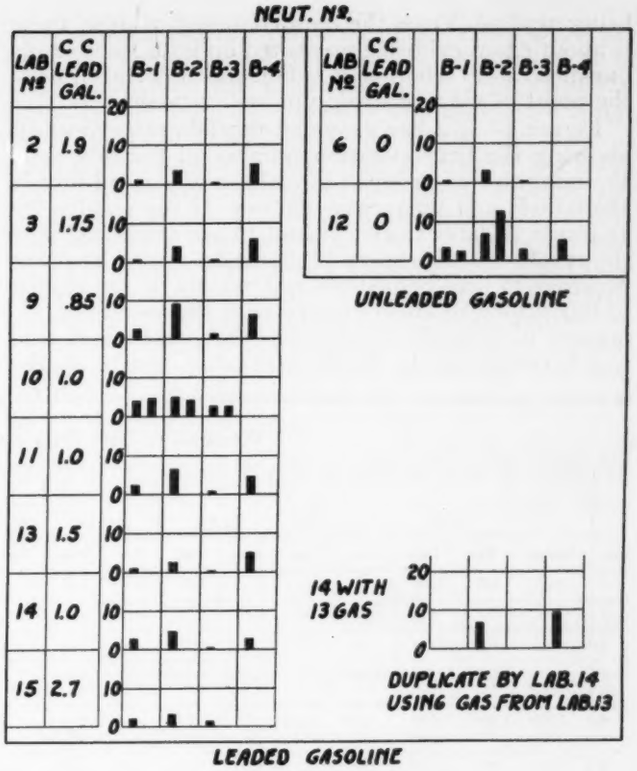


FIGURE 10

secured from laboratory 13, are due to the amount of inhibitor picked up by the crankcase oil from the two different fuels.

The effect of another fuel additive, lead, is still

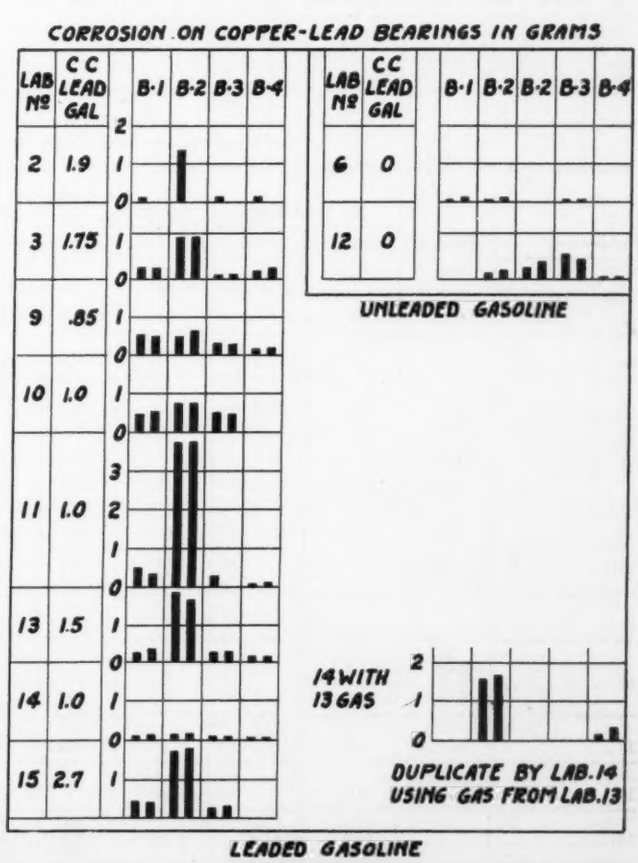


FIGURE 11

being studied. From the data compiled to date, there is about equal evidence presented on both sides of the question, as to whether it is harmful or helpful, from the point of view of oxidation and corrosion.

Figure 10 is a bar graph of the laboratory results showing the neutralization number of the oils, with the laboratories grouped into those who used lead in their fuels and those who did not. If the results, for example, of laboratories 15 and 13 are compared with the results of laboratory 12, it would appear that the presence of lead helped the test results. If the results of laboratory 10 are compared with the results of laboratory 6, it would appear that the presence of lead was harmful. Lastly, if laboratory 2, 3, and 13 results are compared with laboratory 6, the presence of lead in the fuel would not appear to have any measurable influence on the test results. Note laboratory 9 results. This had but .85 cc of lead, but .13% of sulphur in the fuel. It has been suggested that laboratory 9 rerun their data using a fuel similar to that used by laboratory 13.

Note the fact that the neutralization numbers of laboratory 14, using laboratory 13 fuel, for B-2 and B-4 oils coincides more closely with the average laboratory results.

Figure 11 is a graph of copper-lead bearing corrosion plotted for the leaded and unleaded fuels. Somewhat similar comments, as made for the pre-

**Cooperative Test Data on B-1 Oil—36-Hour Results**

| Lab. | Engine | V/100 New | V/100 Used | Con. Carb. New | Con. Carb. Used | % Ash New | % Ash Used | Acid No. New | Acid No. Used | Nap. Insol. Mg./10 gms. New | Nap. Insol. Mg./10 gms. Used | Chl. Sol. Mg./10 gms. New | Chl. Sol. Mg./10 gms. Used | Oil Consump. M.P. Qt. | Fuel | Fuel Consump. 300 cc | Intake Manifold Vacuum " Hg. Start | Intake Manifold Vacuum " Hg. End | Exhaust Back Pressure " Hg. Start | Exhaust Back Pressure " Hg. End |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1941 | 585 | 1,002 | 0.29 | 2.21 | ... | .37 | —0.16 | 1.15 | ... | 170 | ... | 124 | 800 | 1.9cc | 1.16 Min. | 10.7 | 10.6 | 0.5 | 0.5 |
| 3 | 1941 | 581 | 848 | 0.28 | 2.40 | 0.16 | 0.75 | —0.38 | 0.71 | 21 | 142 | 15 | 97.6 | 540 | 1.75cc | 1.31 | 10 | 10 | 1.4 | 1.4 |
| 4 | .... | 602 | 1,097 | .30 | 2.68 | ... | 0.65 | .... | 1.38 | ... | 156 | ... | 121 | 1,135 | 2cc | 1.15 | 11.5 | 11 | 1⅝ | 1.5 |
| 6 | .... | 582 | 1,169 | 0.28 | 1.87 | 0.1432 | .2766 | 0.5 | 0.68 | 7 | 138 | 2 | 123 | 700 | 0cc | 1.42[3] min. .663 lb/bhp/hr. | 13.1 | ... | 1.0 | ... |
| 8 | 1941 | 578 | 992 | .27 | 3.11 | ... | 0.72 | .... | 0.85 | ... | 230 | ... | 145 | 397 | 3cc | .79[3] | 12.1 | ... | 1.4 | ... |
| | 1941 | 578 | 1,016 | .27 | 3.97 | ... | 0.93 | .... | 2.0 | ... | 281 | ... | 74 | 575 | 3cc | .93[3] | 10.7 | ... | 1.7 | ... |
| 9 | 1941 | 580 | 1,053 | 0.23 | 1.6 | 0.14 | 0.41 | —0.10 | 2.50 | None | 115 | None | 94 | ... | 0.85cc | 1.185 | ... | ... | 0.85 | ..... |
| 10 | 1941 Eng. A | 583.8 | 1,418 | 0.28 | 3.26 | 0.16 | 0.55 | —.032 | 4.0 | 8.0[5] | 311[5] | 3.0[5] | 275[5] | 670 | 1cc | ..... | ... | ... | ... | ... |
| | | | | 0.30[4] | 2.87[4] | | | | | | | | | | | | | | | |
| | 1941 Eng. B | 583.8 | 1,361 | 0.28 | 3.03 | 0.16 | 0.68 | —.032 | 4.4 | 8.0[5] | 302[5] | 3.0[5] | 265[5] | 765 | 1cc | ..... | ... | ... | ... | ... |
| | | | | 0.30[4] | 2.76[4] | | | | | | | | | | | | | | | |
| 11 | .... | 596 | 1,102 | 0.271 | 2.092 | 0.161 | 0.650 | 0.07 | 2.55 | 6.2 | 147.1 | 1.8 | 131.5 | 864 | 1cc | .730[3] | 12.0 | 11.5 | 1.4 | 1.4 |
| 12 | 1941 Eng. 1 | 581 | 1,134 | 0.27 | 1.84 | 0.15 | 0.18 | —0.38 | 3.61 | 1.8 | 137.5 | ... | 131.4 | 813 | 0cc | 1.26 | 13.5 | 13.6 | 2.3 | 2.0 |
| | 1941 Eng. 2 | 581 | 1,030 | 0.27 | 1.47 | 0.15 | 0.24 | —0.38 | 2.52 | 1.8 | 91.8 | ... | 86.8 | 1,350 | 0cc | 1.25 | 15.6 | 15.4 | ... | ... |
| 13 | Eng. 4 | 599.7 | 864.0 | 0.27 | 1.92 | 0.165 | 0.518 | — .06 | 1.50 | ... | 97.5 | ... | 72.4 | 1,290 | 1.5cc | 1.21 Min. | 11.9 | 11.5 | 1.2 | 1.2 |
| 14 | 1939 | 606 | 947 | 0.33 | 1.98 | 0.15 | 0.41 | —0.19 | 2.89 | ... | 126.2 | ... | 86.0 | 865 | 1cc | ..... | ... | ... | ... | ... |
| 15 | .... | 407 | 943 | 0.3 | 2.5 | 0.17 | 0.71 | ... | 2.0 | ... | 130 | ..... | 80 | 667 | 2.7cc | 1.315 | 12.3 | ... | 1.1 | ... |
| | | | | | | | | | | | | | | | | | 17.6[7] | | | |

**Cooperative Test Data on B-1 Oil—36-Hour Results**

| Laboratory | Engine | Air Fuel Ratio Start | Air Fuel Ratio End | Spark Advance B.T.D.C. | Ring Wear in Inches, No. 5 Piston Top | Ring Wear in Inches, No. 5 Piston Middle | Ring Wear in Inches, No. 5 Piston Bottom | Bearing Loss Gms. Top | Bearing Loss Gms. Bottom | Bearing Loss Gms. Average | Engine Rating Varnish | Engine Rating Sludge | Engine Rating Total | Oil Pressure Lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1941 | 14.2[14] | .... | .. | .... | .... | .... | .15 | .12 | .135 | 81[2] | 65[2] | 146 | .... |
| 3 | 1941 | 13.8 | .... | 45 | .008 | .009 | .025 | .3404 | .3366 | .3385 | 60.0 | 27 | 87 | .... |
| | | | | | | | | .3361 | .2971 | .3166 | | | | |
| 4 | .... | 14.2 | 14.1 | .. | .002 | .002 | .002 | .32 | .24 | .28 | 106.1 | 71.5 | 177.6 | 13.4 |
| | | | | | | | | .38 | .41 | .395 | 96% | 95.5% | 95.75% | |
| 6 | .... | 15.6 | 16.7 | .. | .002 | .002 | .001 | .0840 | .0492 | .0666 | 71 | 68 | 69.5 | 16.5 |
| | | | | | | | | .1670 | .0516 | .1093 | | | | |
| 8 | 1941 | ..... | .... | .. | .009 | .008 | .016 | .478 | .337 | .4075 | 86 | 51 | 137 | 12 |
| | | | | | | | | .395 | .371 | .383 | 78% | 68% | 73% | |
| | 1941 | 14.2 avg. | .... | .. | .003 | .005 | .009 | .233 | .297 | .315 | 84 | 53 | 137 | .. |
| | | | | | | | | .354 | .351 | .3525 | 76% | 71% | 74% | 10 |
| 9 | 1941 | 14.6 | .... | 52 | .002 | .003 | .005 | .5372 | .6079 | .5726 | 73 | 66 | 139 | 13.5/15 |
| | | | | | | | | .4778 | .5330 | .5054 | | | | |
| 10 | 1941 Eng. A | ..... | .... | 57 | .008 | .008 | .011 | .4430 | .4101 | .4265 | .... | .... | 71 | .... |
| | 1941 Eng. B | ..... | .... | 57 | .006 | .005 | .010 | .6091 | .4444 | .5268 | .... | .... | 75 | .... |
| 11 | .... | 14.5 | 14.4 | .. | .003 | .004 | .005 | .5709 | .4564 | .5137 | 105 | 68 | 173.5 | .... |
| | | | | | | | | .3439 | .3813 | .3616 | | | | |
| 12 | 1941 Eng. 1 | 14.4 | 15.5 | .. | .... | .... | .... | .1711 | .1290 | .1501 | 75.5 | 54.5 | 130 | .... |
| | | | | | | | | .2868 | .1220 | .2044 | 62.9% | 72.6% | 67.75% | |
| | 1941 Eng. 2 | 14.1 | 14.1 | .. | .001 | .000 | .004 | .1270 | .1101 | .1186 | 96 | 64 | 160 | |
| | | | | | | | | .2459 | .1434 | .1947 | 80.0% | 85.3% | 82.7% | .... |
| 13 | Eng. 4 | 14.5 | 14.3 | .. | .0065 | .002 | .004 | .23 | .24 | .235 | 106 | 67.5 | 173.5 | .... |
| | | 14.7[6] | 14.7[6] | | | | .033[12] | .40 | .34 | .37 | | | | |
| 14 | 1939 | 13.6 | .... | .. | .... | .... | .... | .1450 | .1060 | .1255 | .... | .... | .... | .... |
| | | | | | | | | .1560 | .1180 | .1370 | | | | |
| 15 | .... | 14.6 | 14.6 | 52 | .002 | .004 | .004 | .376 | .505 | .4405 | 107 | 63 | 170 | 15.6 |
| | | | | | .0021[9] | .0030[9] | .0040[9] | .366 | .443 | .4045 | 48.7 | 42 | 90.7% | 4.5[8] |
| | | | | | .036[10] | .019[10] | .016[10] | | | | | | | |

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ceding figure, could be made for this curve. Again note the results obtained by laboratory 14 with laboratory 13 fuel.

Figure 12, while taken from a 66⅔ hour report, was believed to be of sufficient interest to reproduce here. Note in these data that in the case of the B-1 oil, the indications are that the presence of the lead was harmful, by all standards given except that of viscosity and engine rating. On the other hand, in the case of both B-2 and B-3 oils, the presence of the lead in the fuel would seem to have helped, or reduced, the oxidation of the oil, as determined by practically all of the standards presented.

All in all, while individual, or isolated, data would seem to point very strongly in one direction or the other, when all of the available data has been assembled, the combined results present a most confused picture. Since the effect of lead in fuels on the oxidation of crankcase oils is not only a very important subject, but one requiring much more work before any tentative conclusions can be reached, it is hoped that this will be the subject of a paper at the January meeting of the Society of Automotive Engineers in Detroit, Michigan.

From this and other data, indications are that some fuel characteristics may have the effect of aiding the oil resist oxidation and resulting deposits and corrosion effects. Further, that all of the types and forms of certain ingredients, principally sulphur, may vary widely in producing inhibiting characteristics. Again, it should be pointed out, that calibration of the test instrument is necessary by means of the reference oil pattern together with a standard test fuel, before it may be used to evaluate lubricating oils for heavy duty service conditions.

However, the point is that fuel specifications are being studied which, it is believed, will have broad enough limits so that all laboratories will have little

**Cooperative Test Data on B-2 Oil—36-Hour Results**

| Lab. | Engine | V/100 New | V/100 Used | Con. Carb. New | Con. Carb. Used | % Ash New | % Ash Used | Acid No. New | Acid No. Used | Nap. Insol. Mg./10 gms. New | Nap. Insol. Mg./10 gms. Used | Chl. Sol. Mg./10 gms. New | Chl. Sol. Mg./10 gms. Used | Oil Consump. M.P. Qt. | Fuel | Fuel Consump. 300 cc | Intake Manifold Vacuum " Hg. Start | Intake Manifold Vacuum " Hg. End | Exhaust Back Pressure " Hg. Start | Exhaust Back Pressure " Hg. End |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1941 | 410 | 736 | 0.11 | 2.58 | ... | 0.29 | 0.05 | 3.63 | ... | 136 | ... | 24 | 800 | 1.9cc | 1.14 | 10.4 | 10.2 | 0.7 | 0.6 |
| 3 | 1941[11] | 425 | 626 | 0.10 | 1.95 | 0.03 | 0.36 | 0.02 | 4.0 | 9.0 | 15.9 | 6.0 | 12.9 | 480 | 175cc. | 1.335 | 10.3 | ... | 2.6 | ... |
| 6 | .... | 410 | 600 | 0.14 | 1.20 | ... | .0168 | 0.10 | 2.95 | 5.0 | 42.0 | 4.0 | 15.0 | 836 | 0cc | .775 lb/bhp/hr. | 13.3 | 9.7 | 1.12 | 1.16 |
| 8 | 1941 | 408 | 601 | 0.09 | 3.7 | ... | 0.67 | ... | 2.7 | ... | 62 | ... | 10 | 920 | 3cc | .78[3] | 12.3 | ... | 1.4 | ... |
| 9 | 1941 | 411 | 860 | 0.02 | 1.91 | 0.001 | 0.14 | Neut. | 9.0 | None | 115 | None | 44 | ... | 0.85cc | 1.285 | ... | ... | 0.80 | ... |
| 10 | 1941 Eng. A | 413.5 | 731 | 0.088<br>0.12[4] | 2.72<br>2.26[4] | ... | 0.38 | 0.025 | 4.8 | 2.0[5] | 184[5] | 0.[5] | 50[5] | 838 | 1cc | ..... | ... | ... | ... | ... |
| | 1941 Eng. B | 413.5 | 751 | 0.088<br>0.12[4] | 2.65<br>2.20[4] | ... | 0.32 | 0.025 | 4.0 | 2.0[5] | 196[5] | 0.[5] | 75[5] | 600 | 1cc | ..... | ... | ... | ... | ... |
| 11 | .... | 406 | 1,313 | 0.076 | 3,412 | 0.005 | 0.846 | 0.022 | 6.3 | 5.6 | 22.5 | 5.6 | 5.1 | 864 | 1cc | .765lb/bhp/hr. | 13.1 | 11.9 | 1.4 | 1.4 |
| 12 | 1941 Eng. 1 | 408 | 821 | 0.10 | 2.05 | 0.01 | 0.02 | 0.03 | 7.01 | 1.0 | 11.6 | ... | 1.5 | 1,383 | 0cc | 1.23 | 13.0 | 14.2 | 2.0 | 1.9 |
| | 1941 Eng. 2 | 408 | 1,205 | 0.10 | 2.02 | 0.01 | 0.06 | 0.03 | 12.63 | 1.0 | 39.3 | ... | 9.3 | 1,590 | 0cc | 1.23 | 14.2 | 13.9 | ... | ... |
| 13 | Eng. 4 | 407.6 | 762 | 0.07 | 2.75 | Nil | 0.425 | 0.03 | 2.26 | ... | 80.6 | ... | 34.3 | 738 | 1.5cc | 1.23 | 11.5 | 10.5 | 1.4 | 1.15 |
| 14 | 1939 | 410 | 618 | 0.15 | 1.98 | ... | 0.18 | 0.05 | 5.18 | ... | 93.8 | ... | 25.6 | 565 | 1cc | ..... | ... | ... | ... | ... |
| 15[13] | .... | 407 | 563 | 0.09 | 1.8 | Nil | 0.35 | ... | 3.2 | ... | 16 | ... | 4.0 | 425 | 2.7cc | 1.325 | 12.9<br>17.0[7] | ... | 1.11 | ... |

**Cooperative Test Data on B-2 Oil—36-Hour Results**

| Laboratory | Engine | Air Fuel Ratio Start | Air Fuel Ratio End | Spark Advance B.T.D.C. | Ring Wear in Inches, No. 5 Piston Top | Middle | Bottom | Bearing Loss Gms. Top | Bottom | Average | Engine Rating Varnish | Sludge | Total | Oil Pressure Lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1941 | 14.2[14] | ..... | .. | .... | .... | .... | 1.13 | 1.49 | 1.36 | 83[1] | 66[2] | 149 | .... |
| 3 | 1941[11] | 14.2 | ..... | 45 | .004 | .003 | .011 | 1.042<br>1.1424 | 1.135<br>1.0976 | 1.089<br>1.12 | .... | .... | 14 | .... |
| 6 | .... | 13.8 | 13.8 | .. | .001 | .003 | .002 | .0446<br>.160 | .0215<br>.0142 | .0381<br>.0871 | 95.5<br>84% | 95.9<br>71% | 191.4<br>77.5% | 16.65 |
| 8 | 1941 | 14.2 | ..... | .. | .006 | .006 | .009 | 1.471<br>1.648 | 1.249<br>1.506 | 1.360<br>1.627 | 100<br>91% | 64<br>85% | 164<br>88% | 11 |
| 9 | 1941 | 14.1 | ..... | 52 | .002 | .004 | .008 | .4691<br>.5086 | .4724<br>.7084 | .4708<br>.6085 | 93 | 63.5 | 156.5 | 13.5/15 |
| 10 | 1941 Eng. A<br>1941 Eng. B | .....<br>..... | .....<br>..... | 57<br>57 | .005<br>.005 | .004<br>.005 | .011<br>.010 | .7348<br>.7335 | .7660<br>.7876 | .7504<br>.7606 | ....<br>.... | ....<br>.... | 76<br>77 | ....<br>.... |
| 11 | .... | 14.4 | 14.5 | .. | .005 | .002 | .004 | 3.5389<br>3.5322 | 3.8600<br>3.9856 | 3.6995<br>3.7589 | 110 | 73 | 183 | .... |
| 12 | 1941 Eng. 1 | 15.1 | 14.4 | .. | .003 | .005 | .010 | .0598<br>.0404 | .0926<br>.1857 | .0762<br>.1130 | 88<br>73.3% | 74<br>98.8% | 162<br>86.05% | ....<br>.... |
| | 1941 Eng. 2 | 14.5 | 14.4 | .. | .000 | .001 | .004 | .3302<br>.5470 | .2344<br>.2886 | .2823<br>.4178 | 98<br>81.6% | 69.5<br>92.8% | 167.5<br>87.2% | .... |
| 13 | Eng 4 | 15.0<br>15.3[6] | 15.0<br>15.7[6] | .. | .024 | .019 | .048<br>.159[12] | 1.63<br>1.48 | 2.04<br>1.72 | 1.84<br>1.65 | 103.5 | 72 | 175.5 | .... |
| 14 | 1939 | 14 | ..... | .. | .... | .... | .... | .171<br>.201 | .139<br>.155 | .155<br>.178 | .... | .... | .... | .... |
| 15[13] | .... | 14.6 | ..... | 52.5 | .002<br>.0020[9]<br>.016[10] | .004<br>.0029[9]<br>.009[10] | .004<br>.0021[9]<br>.013[10] | 1.79<br>1.80 | 1.71<br>1.80 | 1.75<br>1.80 | 110 | 75 | 185 | 15.5<br>3.4[8] |

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difficulty in obtaining the fuel. Since an oil company, in selling its oils, is unable to limit the use of its oil to specific fuels, and since such limitation if it could be enforced, which it probably could not, would be highly undesirable, it is necessary that oil evaluation, with regard to its inherent oxidation resistant properties, should be made with fuels which do not contain any natural inhibitors. By the same token, and for laboratory reproducibility, catalytic agents should also be avoided.

If time and space would permit, it would be highly desirable to submit all of the data, together with the interpretations drawn and conclusions reached, which were used in setting up the control limits for the operating conditions of the test. However, since this course of procedure is obviously impractical, only one or two of the more interesting portions will be discussed.

Rather early in the cooperative program, erratic results were obtained, especially when the results of the 1941 Chevrolet engine were compared with the results of engines produced in preceding years. The cooperative test program was established in January, 1941, based on the current 1941 model engine, but the basis of the data on which the testing procedure was written was on earlier model engines. A few tests had been made on the 1941 engines, and since the engine appeared to be substantially the same as the previous model, it was believed that the proposed test procedure could be used with equally satisfactory results using the 1941 model. However, when the first tests began to be reported by the cooperating laboratories, it appeared that the oils were generally being subjected to more severe conditions in the 1941 than in the 1940 engine.

Tests were then made to study the differences and to determine what factors were responsible for the

**Cooperative Test Data on B-3 Oil—36-Hour Results**

| Lab. | Engine | V/100 New | V/100 Used | Con. Carb. New | Con. Carb. Used | % Ash New | % Ash Used | Acid No. New | Acid No. Used | Nap. Insol. Mg./10 gms. New | Nap. Insol. Mg./10 gms. Used | Chl. Sol. Mg./10 gms. New | Chl. Sol. Mg./10 gms. Used | Oil Consump. M.P. Qt. | Fuel | Fuel Consump. 300 cc | Intake Manifold Vacuum " Hg. Start | Intake Manifold Vacuum " Hg. End | Exhaust Back Pressure " Hg. Start | Exhaust Back Pressure " Hg. End |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1941 | 433 | 512 | 0.46 | 1.54 | ..... | 0.61 | —0.32 | 0.45 | ..... | 60 | .... | 8 | 800 | 1.9cc | 1.15 | 11.1 | 10.4 | 0.5 | 0.7 |
| 3 | 1941 | 438 | 508 | 0.45 | 1.95 | 0.30 | 0.84 | —0.45 | 0.55 | 25 | 47.2 | 9 | 11.9 | 540 | 1.75cc | 1.26 | 9.8 | ... | 2.6 | ... |
| 4 | 1941 | 414 | 551 | 0.55 | 2.32 | ..... | 0.94 | ... | 0.69 | ..... | 52 | ... | 5 | 1,070 | 2cc | 1.25 | 12.5 | 12.0 | 1.25 | 1 |
| 6 | .... | 437 | 475 | 0.48 | 0.88 | .3338 | .3782 | 0.05 | 0.40 | 9.0 | 15.0 | 1.0 | 7.0 | 1,255 | 0cc | .59lb/bhp/hr. | 10.3 | 12.8 | 1.6 | 1.5 |
| 8 | 1941 | 432 | 537 | 0.44 | 2.83 | 0.34 | 0.86 | ..... | 1.6 | ..... | 69 | ..... | 10 | 2250 | 3cc | .81[3] | 13.1 | ..... | 1.3 | ..... |
| 9 | 1941 | 432 | 535 | 0.43 | 1.20 | 0.31 | 0.69 | —0.5 | 1.75 | None | 62 | None | 13 | ..... | 0.85cc | 1.201 | ..... | ..... | 1.0 | ..... |
| 10 | 1941 Eng. A | 434.5 | 565 | 0.43 | 2.24 | 0.31 | 0.82 | —0.4 | 2.3 | 8.0[5] | 43[5] | 1.0[5] | 19.0[5] | 738 | 1cc | ..... | ..... | ..... | ..... | ..... |
| | | ..... | ..... | 0.53[4] | 1.97[4] | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 1941 Eng. B | 434.5 | 571 | 0.43 | 2.01 | 0.31 | 0.73 | —0.40 | 2.2 | 8.0[5] | 68[5] | 1.0[5] | 48[5] | 730 | 1cc | ..... | ..... | ..... | ..... | ..... |
| | | ..... | ..... | 0.55[4] | 1.94[4] | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 11 | .... | 420 | 501 | 0.511 | 1.467 | 0.377 | 0.783 | —0.48 | 0.86 | 0.1 | 32.1 | 0.1 | 5.0 | 432 | 1cc | .693lb/bhp/hr. | 13.5 | 13.6 | 1.4 | 1.4 |
| 12 | 1941 | 430 | 622 | 0.46 | 1.67 | 0.30 | 0.42 | —0.19 | 3.49 | 1.9 | 5.9 | ..... | 0.2 | 1,965 | 0cc | 1.21 | 15.2 | 14.6 | ..... | ..... |
| 13 | Eng. 4 | 418.2 | 481 | 0.50 | 1.45 | 0.356 | 0.663 | —0.21 | 0.62 | ..... | 52.2 | ..... | 15.0 | 978 | 1.5cc | 1.245 | 12.6 | 11.7 | 0.9 | 1.0 |
| 14 | 1939 | 420 | 439 | 0.48 | 1.50 | 0.28 | 0.42 | —0.28 | 0.71 | ..... | 39.9 | ..... | 6.2 | 382 | 1cc | ..... | ..... | ..... | ..... | ..... |
| 15 | .... | 455 | 494 | 0.4 | 1.4 | 0.33 | 0.71 | ..... | 1.7 | ..... | 43 | ..... | 7.0 | 645 | 2.7cc | 1.34 | 12.5<br>17.6[7] | ..... | 0.8 | ..... |

**Cooperative Test Data on B-3 Oil—36-Hour Results**

| Laboratory | Engine | Air Fuel Ratio Start | Air Fuel Ratio End | Spark Advance B.T.D.C. | Ring Wear in Inches, No. 5 Piston Top | Ring Wear in Inches, No. 5 Piston Middle | Ring Wear in Inches, No. 5 Piston Bottom | Bearing Loss Gms. Top | Bearing Loss Gms. Bottom | Bearing Loss Gms. Average | Engine Rating Varnish | Engine Rating Sludge | Engine Rating Total | Oil Pressure Lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1941 | 14.2[14] | .... | .. | .... | .... | .... | 0.11 | 0.10 | 0.105 | 89 | 77 | 166 | .... |
| 3 | 1941 | 14 | .... | 45 | .008 | .009 | .031 | .1431<br>.1844 | .1213<br>.1272 | .1322<br>.1558 | 69 | 28.5 | 97.5 | .... |
| 4 | 1941 | 14.2 | 14.1 | .. | .001 | .002 | .002 | .22<br>.19 | .15<br>.15 | .185<br>.17 | 108.5<br>98.75% | 73.8<br>98% | 182.3<br>98.3% | 16.7 |
| 6 | .... | 13.8 | 14.2 | .. | .001 | .002 | .003 | .0587<br>.0698 | .0461<br>.0442 | .0524<br>.0570 | 87<br>96.4% | 63<br>96.1% | 150<br>96.3% | 16.4 |
| 8 | 1941 | 13.9 | .... | .. | .003 | .004 | .005 | .789<br>.394 | .315<br>.441 | .552<br>.4175 | 99<br>90% | 39<br>79% | 138<br>85% | 10 |
| 9 | 1941 | 13.3 | .... | 52 | .006 | .004 | .004 | .2581<br>.2738 | .2916<br>.2593 | .2748<br>.2665 | 93 | 63.5 | 156.5 | 13.5/15 |
| 10 | 1941 Eng. A | .... | .... | 57 | .005 | .002 | .012 | .5260[15] | .4324[15] | .4792[15] | .... | .... | 91 | .... |
| | 1941 Eng. B | .... | .... | 57 | .005 | .006 | .012 | .5133 | .4041 | .4587 | .... | .... | 91 | .... |
| 11 | .... | 14.4 | 13.8 | .. | .002 | .003 | .004 | .3971[16] | .1251 | .2611 | 110 | 72.5 | 182.5 | .... |
| 12 | 1941 | 14.4 | 14.0 | .. | .001 | .001 | .007 | .5969<br>.6425 | .6759<br>.3708 | .6364<br>.5067 | 102.5<br>85.7% | 71<br>94.8% | 173.5<br>90.25% | .... |
| 13 | Eng. 4 | 13.5[9] | 15.0<br>15.3[9] | .. | .012 | .012 | .021<br>.090[12] | .23<br>.23 | .24<br>.27[17] | .235<br>.25 | 104 | 67.5 | 171.5 | .... |
| 14 | 1939 | 13.5 | .... | .. | .... | .... | .... | .0940<br>.074 | .0470<br>.039 | .0705<br>.0565 | .... | .... | .... | .... |
| 15 | .... | 14.6 | 14.6 | 52 | .002<br>.0023[9]<br>.038[10] | .001<br>.0020[9]<br>.019[10] | .001<br>.0023[9]<br>.013[10] | .218<br>.311 | .339<br>.421 | .2785<br>.366 | 109 | 71 | 180 | 16.3<br>4.8[8] |

*See Notes—Page 133*

increased oxidation being obtained by most of the laboratories.

The 1941 engines being new might permit more metal pick-up by the oil, and this metal might catalyze the oil. There was the fear that the oils used as reference oils might be different from the oils previously used, and on which data had been determined to help in selecting the reference oils. The effect of minor changes in engine design might be another factor.

A number of engine runs were then made, trying to keep all factors constant except the one being studied. The test data were tabulated and studied. Some of the data in connection with these tests are shown in Figures 5, 13, and 14.

The differences did not appear to be due to metal pick-up caused by the use of new engines. It was apparent that the oil company had kept the various lots of oil uniform, since five lots of oil delivered over a period of about a year gave either good or poor results, depending on some other factor. Various engine design factors were studied and it was found that the air-fuel ratio on the 1941 engine was about one ratio leaner than on the 1940 engine, but the test data showed much larger differences in air-fuel ratios in these tests. Investigation showed that these differences were due to accumulations of dirt which had formed in the carburetors in these tests, and this accidental variable gave a clue to the possible cause of the differences in results.

Since increase in viscosity appeared to be a direct function of oxidation and since from these data engine varnish formation would also seem to be a direct function of increase in viscosity for a given oil, other conditions remaining the same, the oxidation of the lubricating oil would, at least for the air-fuel ratio used, appear to be in direct relation with the air-fuel ratio.

Just why air-fuel ratio had the effect it did have was, perhaps for the moment, not too thoroughly understood. However, since it did have the relation,

**Cooperative Test Data on B-4 Oil—36-Hour Results**

| Lab. | Engine | V/100 | | Con. Carb. | | % Ash | | Acid No. | | Nap. Insol. Mg./10 gms. | | Chl. Sol. Mg./10 gms. | | Oil Consump. M.P. Qt. | Fuel | Fuel Consump. 300 cc | Intake Manifold Vacuum " Hg. | | Exhaust Back Pressure " Hg. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | New | Used | New | Used | New | Used | New | Used | New | Used | New | Used | | | | Start | End | Start | End |
| 2 | 1941[18] | 520 | 1,685 | 0.39 | 2.29 | ..... | Nil | 0.05 | 5.25 | ..... | 345 | ..... | 336 | 700 | 1.9cc | 1.14 | 11.1 | 9.7 | 0.5 | 0.7 |
| 3 | 1941[20] | 507 | 2,723 | ..... | 4.3 | 0.05 | 0.23 | 0.10 | 5.95 | 5 | 480 | 2 | 465 | 450 | 1.75cc | 1.34 | 11 | ..... | 2.6 | ..... |
| 6 | 1941 | 508 | 985 | 0.034 | 1.36 | ..... | 0.0156 | 0.10 | 2.45 | 3.0 | 132.0 | 3.0 | 117.0 | 624 | 0cc | 0.868[3] | ..... | 11.6 | 1.3 | 1.5 |
| 8 | 1941 | 507 | 1,665 | 0.02 | 4.24 | ..... | 0.25 | ..... | 3.4 | ..... | 463 | ..... | 382 | 419 | 3cc | 0.84[3] | ..... | 11.7 | ..... | ..... |
| 9 | 1941 | 512 | 1,764 | 0.01 | 2.23 | 0.001 | 0.03 | 0.025 | 6.40 | None | 351 | None | 327 | ... | 0.85cc | 1.212 | ..... | ..... | 0.85 | ..... |
| 10 | .... | 517.3 | 1,643.2 | 0.023 | 2.62 | ..... | 0.17 | 0.1 | 5.0 | 2 | 319 | 2 | 304 | 360 | 1cc | ..... | ..... | ..... | ..... | ..... |
| 11 | .... | 511 | 1,729 | 0.025 | 2.428 | 0.004 | 0.052 | 0.17 | 4.52 | 14.3 | 334 | 12.6 | 324 | 540 | 1cc | 0.793[3] | 12.9 | 11.9 | 1.4 | 1.4 |
| 12 | 1941 | 510 | 1,203 | 0.01 | 1.44 | 0.00 | 0.01 | 0.03 | 5.75 | 0.8 | 167.0 | ..... | 163.0 | 932 | 0.cc | 1.17 | 13 | 13.8 | ..... | ..... |
| 13 | Eng. 4[19] | 515.2 | 1,182 | 0.03 | 2.84 | Nil | .086 | 0.10 | 5.62 | ..... | 36.5 | ..... | 35.7 | 544 | 1.5cc | 1.295 | 12.7 | 11.0 | 0.95 | 1.3 |
| 14 | 1939 | 521 | 951 | 0.04 | 2.18 | ..... | 0.06 | 0.06 | 2.44 | ..... | 179.4 | ..... | 113.8 | 354 | 1cc | ..... | ..... | ..... | ..... | ..... |

**Cooperative Test Data on B-4 Oil—36-Hour Results**

| Laboratory | Engine | Air Fuel Ratio | | Spark Advance B.T.D.C. | Ring Wear in Inches, No. 5 Piston | | | Bearing Loss Gms. | | | Engine Rating | | | Oil Pressure Lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Start | End | | Top | Middle | Bottom | Top | Bottom | Average | Varnish | Sludge | Total | |
| 2 | 1941[18] | 14.0 | ..... | .. | .... | .... | .... | .15 | .16 | .155 | 10 | 3 | 13 | .... |
| 3 | 1941[20] | 13.9 | ..... | 45 | .009 | .011 | .028 | .1576<br>.4461 | .2568<br>.2114 | .2072<br>.3287 | 52.5 | 14 | 66.5 | .... |
| 6 | 1941 | 14.2 | 14.2 | .. | .... | .... | .... | .0360<br>.0205 | .0240<br>.0437 | .030<br>.0321 | 65<br>58% | 45<br>60% | 110<br>58.5% | 16 |
| 8 | 1941 | 14.3 | ..... | .. | .004 | .004 | .003 | .793<br>1.083 | .838<br>1.030 | .8155<br>1.0565 | 64<br>58% | 35<br>47% | 99<br>53% | 10 |
| 9 | 1941 | 13.5 | ..... | .. | .007 | .005 | .013 | .1763<br>.1974 | .1831<br>.1875 | .1797<br>.1925 | 46.5 | 38.5 | 85 | 13.5/15 |
| 10 | .... | ..... | ..... | 52 | .021 | .022 | .03 | .122 | .1239 | .1229 | .... | .... | .... | .... |
| 11 | .... | 14.4 | 14.4 | .. | .001 | .001 | .004 | .0409<br>.1800 | .0585<br>.0598 | .0497<br>.1199 | 76 | 19 | 95 | .... |
| 12 | 1941 | 17.5 | 14.4 | .. | .002 | .001 | .003 | .0504<br>.0453 | .0579<br>.0539 | .05415<br>.0496 | 39<br>32.5% | 30<br>40% | 69<br>36.25% | .... |
| 13 | Eng. 4[19] | 15.5<br>15.4[6] | .....<br>15.9[6] | .. | .003 | .005 | .003<br>.027[12] | .11<br>.16 | .17<br>.10 | .145<br>.13 | 72.5 | 41 | 113.5 | .... |
| 14 | 1939 | 14.0 | ..... | .. | .... | .... | .... | .032<br>.024 | .02<br>.013 | .026<br>.0185 | .... | .... | .... | .... |

NOTES:

[1] Rod bearings, babbitt good, copper lead slightly corroded not rated; timing case cover, main bearings, main journals not rated.
[2] Timing, case cover not rated.
[3] Reported in lb/bhp/hr.
[4] Ramsbottom carbon.
[5] See addenda "Tentative, Forms Method for Examination of Used Oils, II Determination of Naphtha and Chloroform Insolubles".
[6] Englehart.
[7] Absolute pressure.
[8] To connecting rod jets.
[9] Average ring gap increase in inches, all pistons.
[10] Average ring weight loss in grams on all pistons.
[11] Test run only eight hours, run cut because of high acid numbers.
[12] Average oil ring weight loss in grams.
[13] Test was concluded at the end of 14.5 hours.
[14] After 500 miles.
[15] Number 4 bearing was new at 48 hours. Loss shown is only for No. 3 bearing inserts.
[16] One copper lead bearing only installed in this engine. Slight bond failure noted either mechanical or result of corrosion of the upper half.
[17] Weight loss correction for fatigue is .07 grams. Observed loss was .34 grams, corrected loss, therefore, is .27 grams.
[18] The run was stopped at 30 1/3 hours since the engine could not be started after the rest period. The last sample was, therefore, taken after the engine had stood approximately 15 hours, after mush of the sludge had settled.
[19] Duration of test was 32 hours.
[20] Duration of test was 16 hours.

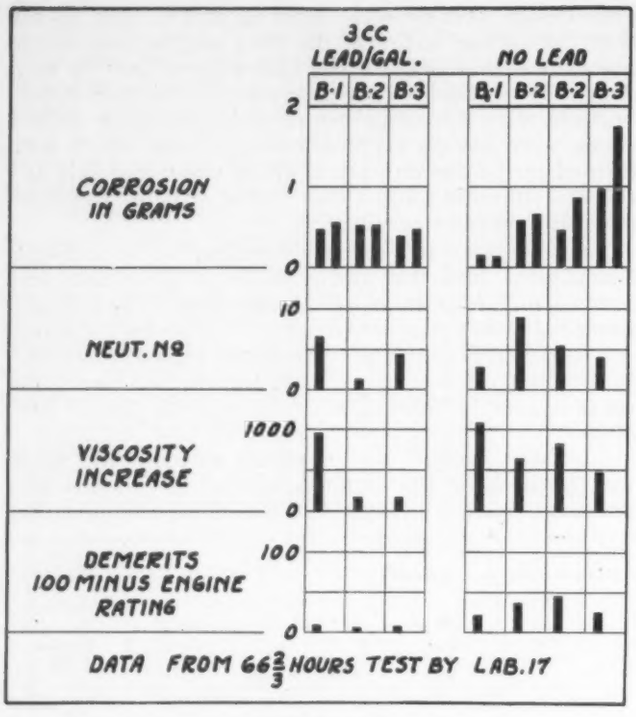


FIGURE 12

control limits for the test program had to be set.

The literature contains a good deal of data on air-fuel ratio[3] which indicated that a ratio of approximately 14.5 to 1 has a tolerance of, perhaps, .5 without being too critical on either side (see Figure 17). Accordingly, this limit was set up for the cooperative laboratories so that the test program could proceed.

However, the question as to why the air-fuel ratio had the effect it did have, still remained to be answered.

At first we suspected that the leaner the mixture the better the combustion in the combustion chamber, and hence the more oxidation. Measurements of piston crown temperatures did not check this theory. It was then suspected that with leaner mixtures the oil would oxidize more readily on the cylinder walls, and that this oxidized oil would then get past the rings and contaminate the oil in the crankcase. This does occur to some extent, but it is apparent from Diesel experience, in which crankcase oil oxidation does not occur with low crankcase oil temperature, even though the air-fuel ratio is very lean, that the oxidation of the oil on the cylinder walls is not the whole story.

Tests were then made to determine whether the principle source of oxidation of the crankcase oil was on the cylinder walls or in the crankcase.

It was noted that the atmosphere in the crankcase varies with different operating conditions, depending upon air-fuel ratio and upon the amount of exhaust gas that gets past the piston rings and mixes with the atmosphere in the crankcase. Tests were made to determine this relationship (see Figure 15) and it was noted that although the oxygen content of the crankcase remained about the same with different air-fuel ratios, the amount of carbon monoxide increased greatly with a rich setting of the carburetor.

Tests were then made with different air-fuel ratios and with different atmospheres in the crankcase. To obtain the effect of a rich air-fuel ratio in the crankcase with a lean air-fuel ratio in the combustion chamber, two engines with different air-fuel ratios were set up, side by side, and a portion of exhaust from the "rich" engine was passed into the crankcase of the "lean" engine. In another test, to obtain the possible effect of a higher oxygen content in the crankcase, air was passed through the crankcase. Other tests were made under normal conditions with both lean and rich air-fuel ratios. The data from these tests are shown in Figure 16.

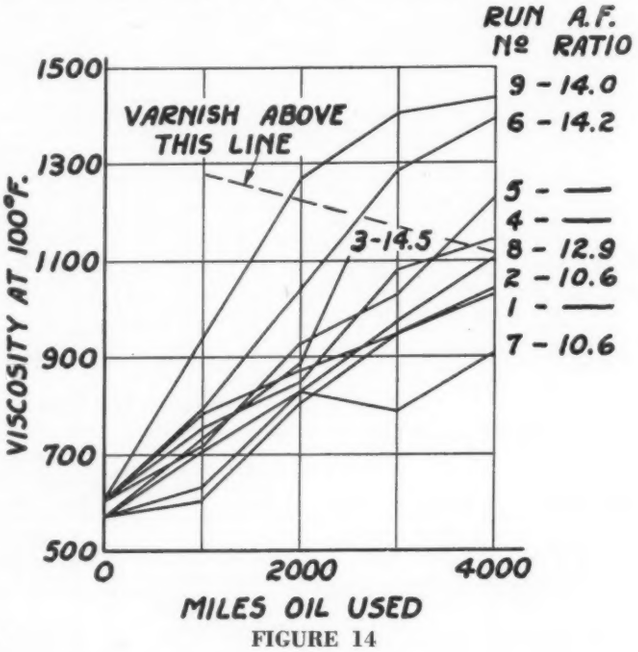


FIGURE 14

It is apparent from these tests that a very large amount of the oxidation of the crankcase oil occurs in the crankcase and that carbon monoxide (or possibly hydrogen, or other reducing gas) is the material that, by acting as an inhibitor in the crankcase, decreases the rate of oxidation when the air-fuel ratio is rich. Of course, in order to prevent the oxidation of the crankcase oil, when the air-fuel ratio is "lean" and there can be no inhibiting effect of carbon monoxide in the crankcase, some other suitable inhibitor should be present in the crankcase oil.

Obviously, for a test procedure, the best setting for any controlling operating specification is such that a fair plus or minus tolerance figure will have little ef-

[3] D'Alleva, B. A., and Lovell, W. G., Research Laboratory Division, General Motors Corporation, "Relation of Exhaust Gas Composition to Air-Fuel Ratio."

| RUN NO | ENGINE MODEL | ENGINE NO | RUN ON THE ENGINE | OIL LOT | RINGS | AIR FUEL RATIO |
|---|---|---|---|---|---|---|
| 1 | 1940 | 1 | X | A | OLD | — |
| 2 | 1940 | 2 | Y | B | OLD | 10.6 |
| 3 | 1940 | 2 | Z | C | OLD | 14.5 |
| 4 | 1941 | 3 | 1 | D | NEW | — |
| 5 | 1941 | 3 | 2 | D | NEW | — |
| 6 | 1941 | 3 | 3 | D | OLD | 14.2 |
| 7 | 1941 | 3 | 5 | C | NEW | 10.6 |
| 8 | 1941 | 3 | 6 | D | NEW | 14.0 |
| 9 | 1941 | 4 | 2 | E | NEW | 12.9 |

FIGURE 13

**FIGURE 15**
**Relation of Air Fuel Ratio to Crankcase Atmosphere and Exhaust Gas**

| Test No. | Test Conditions | Source of Sample | Gas Analysis $CO_2$ | Gas Analysis $O_2$ | Gas Analysis CO | Air Fuel Ratio |
|---|---|---|---|---|---|---|
| A | 3150 R.P.M. road load.... | Exhaust | 14.2 | 0.5 | 0.2 | |
| | | Crankcase | 2.5 | 17.0 | 0.3 | 15.0 |
| B | 380 R.P.M. idling..... | Exhaust | 4.1 | 5.5* | 11.6 | |
| | | Crankcase | 1.0 | 17.4 | 2.9 | 8.9* |
| C | 3150 R.P.M. road load.... | Exhaust | 7.3 | 0.0 | 10.6 | |
| | | Crankcase | 1.8 | 16.1 | 2.9 | 10.4 |

* Carburetor set too rich to idle perfectly and there was some "missing"; therefore air fuel ratio is only approximate.

fect on the test results. A ratio of 14.5 to 1 was such a specification, since a plus or minus .5 ratio on either side seemed to affect the results but little. Further, a 14.5 ratio is a ratio quite comparable with field experience today, and from the point of view of fuel economy, it would appear necessary that the gasoline engine be run on the lean side.

There was one drawback, however, to this ratio. Under the test conditions as then specified, the test, using a 14.5 air-fuel ratio with all other conditions remaining the same was too severe, since, from the results just shown, the carbon monoxide in the crankcase acts as an addition inhibitor of oxidation.

Beginning somewhat prior to, and then running simultaneous with, the air-fuel ratio work, was a series of runs, the object of which was to determine as carefully as possible, the effect of oil sump temperature. For example, Figure 18 illustrates the point that an SAE 10 oil can be made to pass the test, all conditions remaining the same, using a 12.8 to 1 air-fuel ratio with the proper temperature adjustment.

These data then roughly establish the maximum conditions under which the straight high V.I. oil of SAE 10 grade will not form varnish.

These and other runs, indicated that, using 200° F. as the water temperature, a wide range of test severity — from that which would permit a straight SAE 10 grade, high V.I. oil to "pass," to that which would "fail" the best commercial heavy duty oil of the SAE 30 grade — is obtainable by simply varying air-fuel ratio and oil sump temperature. Further, a 200° F. water temperature in service is not uncommon for heavy duty conditions of operation.

Therefore, a series of tests was then run in an effort to determine the desirable oil sump temperature for the selected air-fuel ratio. Figure 19 illustrates the data for a high V.I. oil of the SAE 10 grade, plus an inhibitor only. In other words, this oil is not the best all-around heavy duty oil, but the

**FIGURE 16**
**Effect of Air Fuel Ratio**

| Test No. | Air-Fuel Ratio | Special Conditions | Exhaust Gas $CO_2$ | Exhaust Gas $O_2$ | Exhaust Gas CO | Crankcase Oil (1000 Mi.) Neut. No. | Naph. Insol. | Con. Carb. | Vis. @ 100° F. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 14.2 | Lean Air-Fuel Ratio | 13.9 | 0.3 | 0.9 | 2.23 | .46 | 1.58 | 267 |
| 2 | 15.1* | * | 14.3 | 0.7 | 0.4 | .45 | .84 | .83 | 206 |
| | | | 4.3† | 10.1† | 5.3† | | | | |
| 3 | 14.2 | ‡ | 13.8 | 0.1 | 2.0 | 1.45 | .97 | 1.71 | 283 |
| 4 | 9.8 | Rich Air-Fuel Ratio | 6.6 | 0.0 | 13.4 | .95 | .70 | 1.04 | 215 |

* Exhaust gas from another engine with very rich carburetor was passed into the crankcase.
† Atmosphere of crankcase due to passing exhaust gas from "rich" air-fuel ratio engine through crankcase.
‡ 3 cubic feet of air per minute was passed through the crankcase.

combination is a step better, so to speak, than the oil used for Figure 18.

The data indicates heavy varnish in 33 hours, if the oil sump is held at 280° F., and considerably less if this temperature is dropped to 265° F. Then, if the air-fuel ratio is stepped up to about the selected range, a further drop in temperature is indicated to just "pass" this "half-way" heavy duty oil. Therefore, 240° F. is in the range of, and slightly below what might be termed a "critical oil sump" temperature for these conditions for this oil. Since the oil

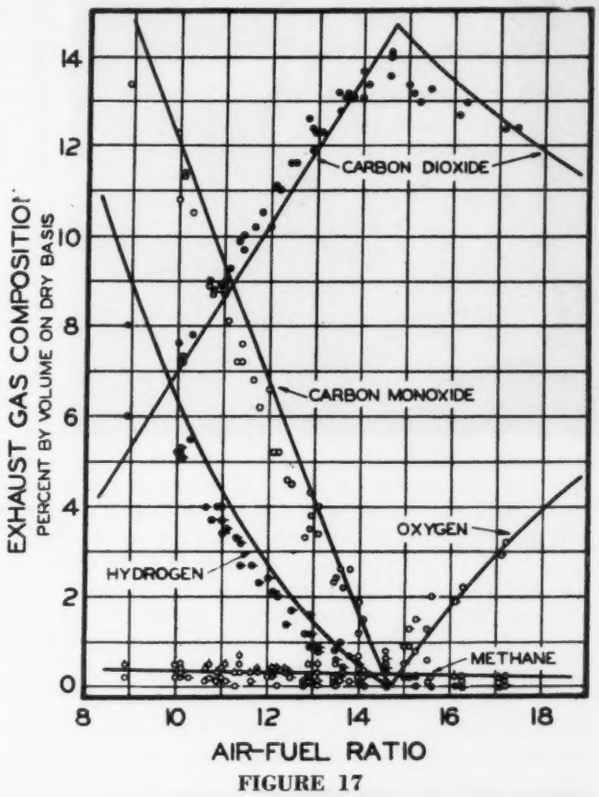


**FIGURE 17**

with an inhibitor is somewhat better for these operating conditions than is the oil without the additive (see Figure 18) an increase in air-fuel ratio, within allowable limits, should not have too great an effect. This point is demonstrated by the last run data of Figure 19.

These data, together with other data and information, indicated that, (1) the severity of the test should be lessened with decreased viscosity of the oil tests; (2) that oil sump temperature was the controlling factor once air-fuel ratio was held in, what might be termed, the insensitive range, which was from about 14 to 15 to 1, all other conditions being held constant. The problem, therefore, became one of setting the test conditions such that, from the point of view of heavy duty operating conditions, a good commercial oil would "pass," while a medium or poor oil would "fail" to a lesser or greater extent.

There were two more variables which were some-

**FIGURE 18**
**High V.I.—10W Straight Mineral Oil (Air Fuel Ratio 12.8)**

| Water °F. | Oil °F. | Hours for Varnish to form on Piston |
|---|---|---|
| 200 | 280 | Between 8 and 16 hours. |
| 200 | 250 | Between 24 and 32 hours. |
| 180 | 250 | Over 67 hours. |
| 200 | 225 | Over 67 hours. |

Top view of pan heater. Note that heating elements may be removed and fans may be used to blow air through the same openings used by the heating element.



Side view of pan heater showing heating elements in place

**FIGURE 19**
**High V.I.—10W Mineral Oil Plus Inhibitor**
**(Water 200° F.)**

| Oil °F. | Air-Fuel Ratio | Hours | Oxidation |
|---|---|---|---|
| 280 | 13.2 | 33 | Very bad. |
| 265 | 13.3 | 33 | Fairly bad. |
| 240 | 13.85 | 33 | Very slight. |
| 240 | 15.3 | 67 | Slight. |

**FIGURE 20**
**Sub-Committee B-3 Oil**
**(Water 200° F.)**

| Fill (Qts.) | Hours | Air-Fuel Ratio | Oil °F. | Engine Rating |
|---|---|---|---|---|
| 5 | 67 | 12.8 | 280 | 108.0 |
| 5 | 67 | 13.8 | 280 | 87.5 |
| 5 | 67 | 13.8 | 265 | 101.5 |
| 4 | 36 | 13.8 | 280 | 97.5 |

what inconspicuous because, for some reason or other, they had been sort of tacitly accepted as a test condition. They were duration of run and sump original fill.

Since the oxidation of oils is, within limits, a function of time times temperature, and, since the time necessary to perform any laboratory test is a vital consideration in the commercial practicability of that test, it was thought that it would be well worthwhile to return to the original oil sump temperature and determine the time required to produce the test pattern for the reference oils, with the preferred air-fuel ratio.

Figure 20 illustrates, briefly, some data indicating by engine rating the fact that after a series of test runs on B-3 oil, the combination of four quarts fill, and maintaining 280° F. oil sump temperature, that a test of 36 hours was satisfactory for the oil tested. Similar work on the other oils gave comparable results.

We have briefly tried to present a few of the high spots encountered. We have attempted to select enough typical data to give a sort of bird's eye view of the work which a few of the laboratories have carried on rather intensively in an effort to make possible production multi-cylinder engine testing, in and between laboratories, a practical method for the evaluation of petroleum products.

Much data has, of necessity, been omitted for lack of space, but its indications are in the same direction as the data herein contained. It should be pointed out that much of this paper has been to demonstrate by means of typical data in chronological order, the rather solid foundation on which the present test procedure is based.

The 36 hour test procedure is, in reality, simple enough that any laboratory can, with some little practice, obtain results which are not only reproducible, but also which check the results of other laboratories, and of the field.

Perhaps it should again be pointed out that the basis upon which this work was started was that of developing a laboratory test procedure for corrosion and oxidation which would would rate test oils as they are found to be rated in service.

Further, that in seeking to obtain a standardized Chevrolet varnish test procedure, it was with the thought in mind that this procedure, plus the Caterpillar test series, would adequately define a motor oil for heavy duty service conditions.

It should be emphasized that the purpose of this test procedure is for the oxidation specification and definition of only heavy duty oils for gasoline and Diesel engine. For milder service, other oils may be not only entirely satisfactory, but may even be more desirable. A test procedure, or procedures, for the evaluation of oils for types of service, other than heavy duty, will probably be one of the future activities of the present committee.

In conclusion, we believe that:

1. By means of carefully controlled operating conditions, production multi-cylinder engines can be used, in conjunction with a series of standard test oils, to give a test pattern for these oils which are reproducible in themselves, and which will coincide with results obtained on these oils in service;

2. As the proper test oil pattern is obtained, a valuable and useful means of testing unknown oils is made possible by describing the unknown oil in terms of the test pattern of the known oils;

3. The description, or specification, of heavy duty motor oils, for oxidation and corrosion characteristics is, for the moment, at least, most easily achieved by evaluating this type of oil in terms of a known test oil pattern;

4. The 36 hour Engine Test Procedure is a satisfactory method for the evaluation of oils for heavy duty service with respect to their oxidation characteristics, but that other tests are required to measure certain other properties, such as resistance to ring sticking, resistance to valve sticking, tendency to form carbon in various locations in and around the combustion chamber, etc.;

5. Not only can unknown oils be evaluated by means of the known test oil pattern, but so can engines of both present and future design.

## Bearing Clearance

Probably the most difficult portion of the 36-hour test procedure to understand, is that portion dealing with the "snap fit" of the copper-lead bearings. In the hope of clarifying the description, a series of pictures has been prepared, using a method which has been found to be highly satisfactory.*

The method involves the use of rippons of extremely soft lead strips, which will deform, or flatten out, under very little pressure.

Figure 3 shows the cap ready to be installed, with the lead strip in place. Note that the strip is placed parallel with the journal.

Figure 4 illustrates the tightening of the cap nuts using a torque wrench. It will be found that 45 to 50 foot pounds is generally about right. The connecting rod should then be oscillated somewhat to cause the lead to flow. A light file scratch across the nut and bolt will be sufficient to indicate the exact place to where the nut is drawn down.

Figure 5 shows the appearance, after the cap is removed, of the lead strip before removal. The lead strip usually breaks into three or four pieces. The fractured pieces are carefully removed and measured. A clearance of .0015 inch to .0020 inch will generally give the best results. However, clearances up to .0035 inch will usually permit the bearing to run through the 36-hour test, though they may be somewhat noisy.

After the measurement has been found to be within the specified clearances, the bearing is re-assembled,

[*Continued on page 142*]

* Method suggested by Mr. John K. Anthony—The Cleveland Graphite Bronze Company.

# Progress Report on the Hydrocarbons In the Kerosine Fraction of Petroleum API Research Project 6

FREDERICK D. ROSSINI, National Bureau of Standards
and
BEVERIDGE J. MAIRN, Senior Research Associate, API Research Project 6

**IN THIS progress report from API Research Project 6, on that part of its work dealing with the isolation and identification of hydrocarbons in the kerosine fraction of petroleum, the following topics are discussed: present status of the work on the gasoline and kerosine fractions; outline of the separation of the kerosine fraction; properties of the hydrocarbons isolated; other hydrocarbons likely to be separated; amounts of the hydrocarbons in the kerosine fraction and in the original crude petroleum; significance of the work to the petroleum industry.**

**This paper was presented by J. Bennett Hill, Sun Oil Company; chairman, Advisory Committee, API Research Project 6, to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 5, 1941.**

IN PREVIOUS reports on API Research Project 6, there have been described the results of the work on the gasoline and the lubricant fractions of the crude petroleum under investigation. The work on the gasoline fraction to date has resulted in the isolation and identification of 49 hydrocarbons of the range from $C_5$ to $C_{10}$, and has provided quantitative data as to their relative amounts. As this number of hydrocarbons has been found to constitute somewhat over half of the gasoline fraction, it appears that, from a practical standpoint, the gasoline fraction at least is less complex than had been supposed originally. In the work on the gasoline fraction, the project has developed special techniques and methods of separation, a number of which have been found useful by the research, development, and testing laboratories in the industry.

The work on the lubricant fraction, on the other hand, has substantiated beliefs as to the complexity of the material. In this work, new methods had to be developed to meet the increased difficulties of the separations involved. However, no pure hydrocarbons were isolated. Instead, there were obtained a series of fractions of sufficient homogeneity (with respect to size and type of molecules) to permit fairly definite conclusions to be drawn as to their general molecular structures. As sufficient data on the properties of pure hydrocarbons of the lubricant range are not yet available for the complete identification of the fractions which would be obtained on further resolution of the lubricant fraction, the Advisory Committee agreed with the staff of Project 6 that it would be best to hold further work on the lubricant fraction in abeyance until more data on pure hydrocarbons of high molecular weight became available from API Research Project 42 and other sources.

In 1938 the project began the investigation of the kerosine fraction. In some respects, this study holds promise of results even more interesting than those already reported on the gasoline and lubricant fractions. In the kerosine fraction, the number of carbon atoms in the molecule is large enough to permit of a wide variety of molecular structures. At the same time, our newly developed methods of separation are succeeding in the isolation of the more abundant of these difficultly separable hydrocarbons. It is hoped that this study on the kerosine fraction will throw considerable light on the relative abundance of the different types of hydrocarbons in the gas-oil and even in the lubricant fraction.

The work on the gasoline fraction already has shown that the more abundant *iso*paraffins are those less highly branched; that naphthenes with both five- and six-membered rings occur in important amounts; and that aromatic hydrocarbons with ethyl and propyl groups are present to a greater extent than in coal tar, our hitherto most important source of aromatics. Questions such as the following cannot be answered from the results on the gasoline fraction because of the insufficient number of carbon atoms per molecule, but should be answered by the work on the kerosine fraction:

1. Do compounds containing both cyclopentane and cyclohexane rings in the same molecule occur in petroleum?
2. Do compounds in which rings are linked through a single carbon atom occur?
3. Do compounds occur which contain an aromatic ring linked through two common carbon atoms to a cyclopentane ring, as in indane and its homologs?
4. How do the amounts of the normal and *iso*paraffins change as one passes from the gasoline to the kerosine and higher-boiling fractions?
5. The work on the lubricant fraction indicated that there were in it no significant amounts of *iso*paraffins.[2, 9] Where, and how sharply, does the content of *iso*paraffins drop to this low value, as one passes from the gasoline to the lubricant fraction?

This paper represents the first progress report to the American Petroleum Institute on the investigation of the kerosine fraction of petroleum by its Research Project 6. The starting material was that portion of the petroleum* boiling in the range 200 to 230° C (392 to 446° F) at a pressure of 1 atmosphere. These particular limits were set primarily because they encompass only one normal paraffin hydrocarbon, viz., *n*dodecane, which normally boils at 216° C. The two neighboring

normal paraffins, *n*undecane and *n*tridecane, normally boil at 196 and 236° C, respectively.

The material of the range 200 to 230° C at 1 atmosphere † to date has been separated completely into three lots: I, one lot consisting substantially of all of the normal paraffin, *n*dodecane; II, one lot of fractions consisting substantially of all of the aromatic hydrocarbons; and, III, one lot of fractions consisting of mixtures of the branched-chain or *iso*paraffins and the naphthenes or cycloparaffins. Seven aromatic hydrocarbons have been isolated and identified from lot II.

The current work consists in the separation of additional aromatic hydrocarbons from lot II, and the separation of the fractions of lot III into *iso*paraffins on the one hand and naphthenes on the other. When the number of hydrocarbons so far determined in the gasoline and kerosine fractions. Under the name of each hydrocarbon appears its boiling point at 1 atmosphere in °C. The displacement to the right of the blocks showing the aromatic hydrocarbons arises from the fact that, in the distillation of the original mixture of hydrocarbons, the aromatic hydrocarbons usually appear in the distillate with normally lower-boiling hydrocarbons of the other classes. The doubly cross-hatched blocks indicate those portions in which all of the theoretically possible hydrocarbons have been determined. The singly cross-hatched blocks indicate those portions whose analysis is considered substantially complete even though only a few of the possible hydrocarbons have been actually isolated from them. The portions

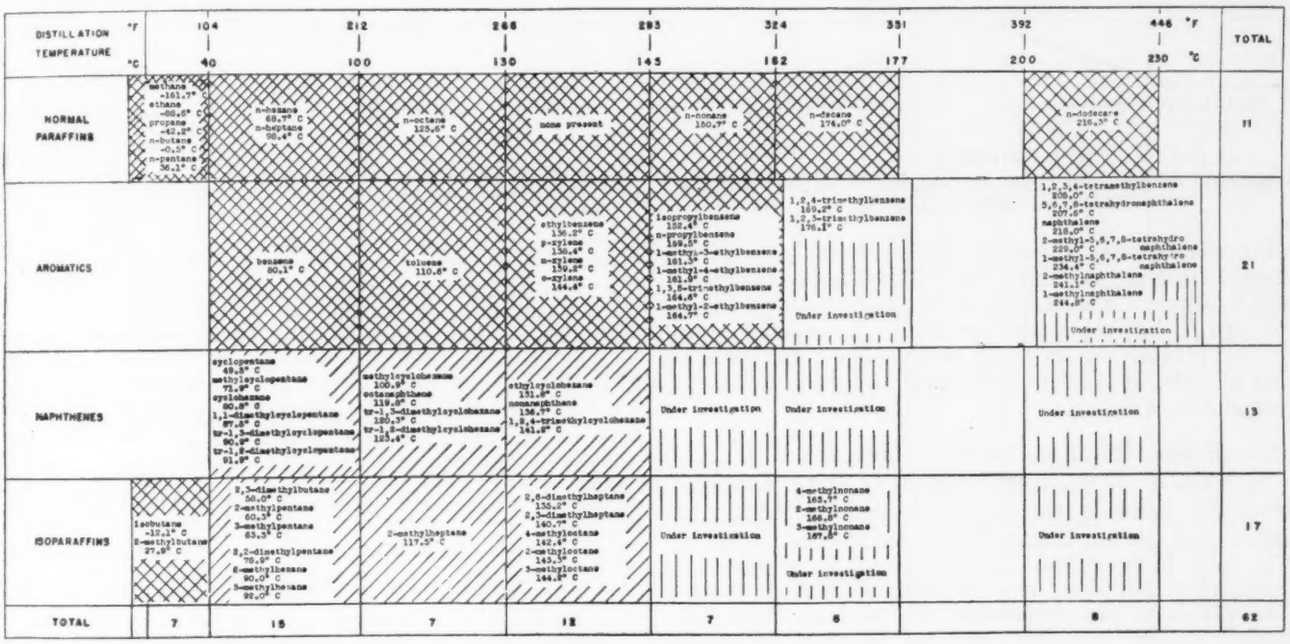


**FIGURE 1**

**Status of the analysis of hydrocarbons in the gasoline and kerosine fractions of petroleum by API Research Project 6 at the National Bureau of Standards, as of September, 1941.**

*iso*paraffins and the naphthenes sufficiently well are segregated by class, the separation of pure hydrocarbon compounds from them will begin.

## Present Status of the Work on the Gasoline and Kerosine Fractions

For the purpose of orientation, there is shown in Figure 1 the present status of the investigation of the hydrocarbons in the gasoline and the kerosine fractions by API Research Project 6, as of September 1941. The non-uniform horizontal scale at the top of the chart gives the distillation temperature in °C and °F. On the margin at the left, the material is shown divided into four classes: normal paraffins, aromatics, naphthenes or cycloparaffins, and branched-chain or *iso*paraffins. The distillation temperatures are divided substantially according to the way in which the material actually was investigated. The row at the bottom gives the number of hydrocarbons isolated from the various portions. The column at the extreme right gives the number of isolated hydrocarbons of the four classes. The block at the lower right corner of the chart gives the total

* For a description of this petroleum, which was from the Mid-Continent Field, see references 1 and 2 in the bibliography.

† In the laboratory, the simple distillation of the material actually is performed at a pressure of 57 mm mercury, with a consequent lowering of temperature of about 86° C.

under investigation at the present time are so marked, and are shown with vertical lines. The material distilling in the range 177 to 200° C has not yet been investigated at all.

From this chart, the relation of the work on the kerosine fraction to the work on the gasoline fraction is evident. In what follows, there is given a more detailed account of the work on the kerosine fraction and some discussion of its significance to the petroleum industry.

## Outline of the Separation of the Kerosine Fraction

A schematic diagram outlining the separation of the kerosine fraction [3, 4] into: I, the normal paraffin; II, the fractions of aromatic hydrocarbons; and III, the fractions consisting of mixtures of *iso*paraffins and naphthenes, is shown in Figure 2.

Figure 3 shows a schematic diagram outlining the separation of seven hydrocarbons from the aromatic fractions. [3, 4] The isolation of additional hydrocarbons from this material is under way.

Figure 4 shows a schematic diagram outlining the separation of the *iso*paraffins from the naphthenes. As indicated, the material of the range 200 to 220° C (at 1 atmosphere) is being separated by azeotropic distillation, whereas the material of the range 220 to 230° C

(at 1 atmosphere) is being separated by extraction. This azeotropic distillation[5] is being performed at a pressure of 770 mm mercury, with diethylene glycol monomethyl ether as the azeotrope-forming substance. The extraction is being performed at about 10° C, with methyl formate as the solvent, in 56-foot columns operating with reflux. These two different methods deliberately are being used in order to develop the technique and to make a comparison of the overall efficiency of the two. When the separation of the *iso*paraffins from the naphthenes substantially is completed, the separation of pure *iso*paraffin compounds and pure naphthene compounds will begin.

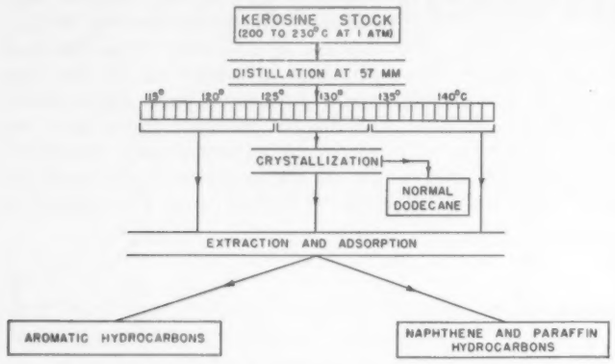


**FIGURE 2**
**Schematic diagram showing the separation of the kerosine fraction, 200° to 230° C.**

### Properties of the Hydrocarbons Isolated

In Table 1 are listed the eight hydrocarbons isolated from the kerosine fraction, with their properties as determined at the National Bureau of Standards.[3, 4] For each hydrocarbon there is given the amount of impurity in the "best" lot of it isolated from petroleum. The values of the properties reported have been corrected to zero impurity, and are believed to be the values of the properties for the absolutely pure hydrocarbons within the limits indicated. Actually, with the exception of 5,6,7,8-tetrahydronaphthalene, tetralin, in which the amount of impurity was 0.015 mole fraction, the "best" lots of these hydrocarbons were so pure that there was no significant change in the values of the properties on extrapolation to zero impurity. Without exception, each of the "best" lots of these eight hydrocarbons from petroleum was, as far as is known to the authors, purer than any lots of the same hydrocarbons previously prepared, synthetically or otherwise. Following the established procedure in the work of Project 6, the freezing points and amounts of impurity in these hydrocarbons were determined from time-temperature freezing and melting curves.[6] The boiling points were determined in a recently constructed apparatus with a platinum resistance thermometer.[7] The refractive indices were determined, for monochromatic light of the **D** line of sodium and the **F** and **C** lines of hydrogen, in the Optical Instruments Section, and the densities in the Capacity and Density Section, at the National Bureau of Standards.

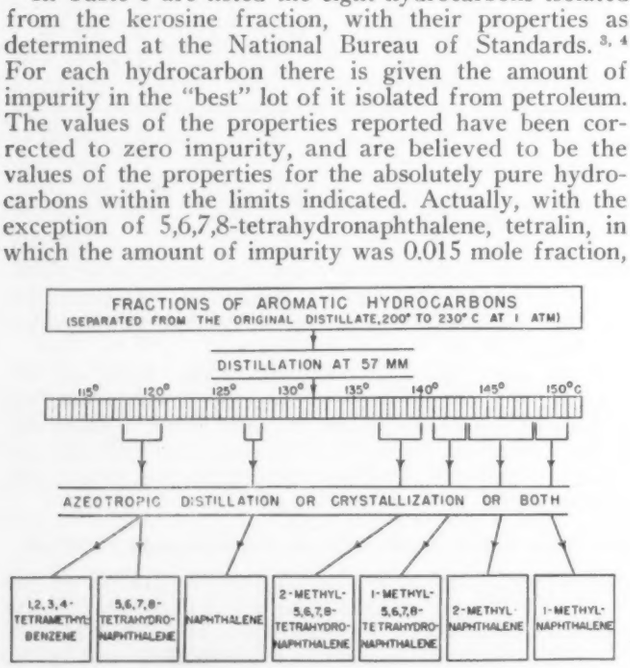


**FIGURE 3**
**Schematic diagram showing the isolation of seven hydrocarbons from the aromatic portion of the kerosine fraction.**

### Amounts of the Hydrocarbons in the Kerosine Fraction and in the Original Petroleum

After the distillate of the range 200 to 230° C had been separated as shown in Figure 2, the material was distributed as follows:

| Lot | Material | Percent by Volume of the Distillate 200 to 230° C |
|---|---|---|
| I | Normal paraffin | 13.6 |
| II | Aromatic hydrocarbons | 19.1 |
| III | *Iso*paraffins and naphthenes | 67.3 |
| | Total | 100 |

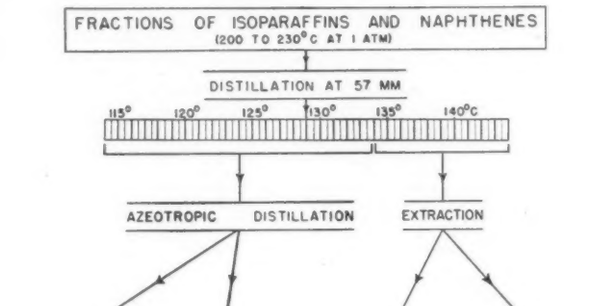
FRACTIONS OF ISOPARAFFINS AND NAPHTHENES
(200 TO 230°C AT 1 ATM)
DISTILLATION AT 57 MM
115° 120° 125° 130° 135° 140°C
AZEOTROPIC DISTILLATION
EXTRACTION
FRACTIONS OF ISOPARAFFINS (200° TO 220° C) AT 1 ATM
FRACTIONS OF NAPHTHENES (200° TO 220° C) AT 1 ATM
FRACTIONS OF ISOPARAFFINS (220° TO 230° C) AT 1 ATM
FRACTIONS OF NAPHTHENES (220° TO 230° C) AT 1 ATM

**FIGURE 4**
**Schematic diagram showing the separation of the *iso*paraffins from the naphthenes.**

The processing has not yet reached the stage where an accurate value can be given for the relative amounts of the *iso*paraffins and naphthenes. Of the eight individual hydrocarbons actually isolated, the amounts in the petroleum are estimated to be as shown in Table 2, wherein are given the following data: the name of the hydro-

**TABLE 2**
**Amounts of the hydrocarbons in the kerosine fraction and in the original petroleum.**

| Hydrocarbon | Amount Constituted by the Given Hydrocarbon | |
|---|---|---|
| | Percent by Volume of the Distillate 200 to 230° C | Estimated Percent by Volume of the Original Crude Petroleum |
| *n*Dodecane | 13.6 ±0.8 | 1.0 |
| 1,2,3,4-Tetramethylbenzene | 1.06 ±0.07 | 0.078 |
| 5,6,7,8-Tetrahydronaphthalene | 0.27 ±0.03 | 0.020 |
| 1-Methyl-5,6,7,8-tetrahydronaphthalene | 0.65 ±0.12 | 0.048 |
| 2-Methyl-5,6,7,8-tetrahydronaphthalene | 0.68 ±0.06 | 0.050 |
| Naphthalene | 0.46 ±0.04 | 0.034 |
| 1-Methylnaphthalene | 0.84 ±0.06 | 0.062 |
| 2-Methylnaphthalene | 1.80 ±0.10 | 0.132 |
| Total | 19.4 ±0.8 | 1.4 |

carbon; the percent by volume of the original distillate, 200 to 230° C, which is constituted by the given hydrocarbon; and the estimated percent by volume of the original crude petroleum which is constituted by the given hydrocarbon. The values in the last column are subject to some change when there become available more accurate data on the relation between the volume of the distillate 200 to 230° C and that of the original petroleum from which it came. The values in the other column are believed to be subject to no change beyond the assigned uncertainties.

From the values presented here, the following points may be noted with regard to the distillate 200 to 230° C:

a. All of the normal paraffin and 30 percent of the aromatic portion have been resolved with respect to pure compounds. The total resolved material represents about 20 percent of the distillate 200 to 230° C.

b. There remains to be resolved 70 percent of the aromatic portion and all of the portion containing the *iso*paraffins and naphthenes. The total unresolved material represents about 80 percent of the distillate of the range 200 to 230° C.

c. There is a more or less regular relation in the relative abundance of naphthalene, 1-methylnaphthalene,

**TABLE 1**
**Properties of hydrocarbons isolated from the kerosine fraction.**
**(Values of properties are extrapolated to zero impurity.)**

| Name | Formula | Structure (conventional) (hydrogen atoms omitted) | Amount of impurity in "best" lot from petroleum | Boiling point at 1 atm | Freezing point in air at 1 atm | Density at 20°C | Density at 25°C | Refractive Index $N_D$ at 20°C | Refractive Index $N_D$ at 25°C | Specific Dispersion $(N_F - N_C)/d$ at 20°C | Specific Dispersion $(N_F - N_C)/d$ at 25°C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mole fraction | °C | °C | g/mL | g/mL | | | | |
| 1,2,3,4-tetramethylbenzene (prehnitene) | $C_{10}H_{14}$ |  | 0.0006 ±0.0001 | **205.04** ±0.03 | -6.25 ±0.01 | 0.9053 ±0.0001 | 0.9015 ±0.0001 | 1.52013 ±0.00007 | 1.51811 ±0.00007 | 0.01734 ±0.00005 | 0.01732 ±0.00005 |
| 5,6,7,8-tetrahydronaphthalene (tetralin) | $C_{10}H_{12}$ |  | 0.015 ±0.002 | 207.57 ±0.10 | -35.80 ±0.02 | 0.9702 ±0.0002 | 0.9662 ±0.0002 | 1.54135 ±0.00015 | 1.53919 ±0.00015 | 0.01665 ±0.00010 | 0.01655 ±0.00010 |
| n-dodecane | $C_{12}H_{26}$ |  | 0.0080 ±0.0004 | 216.24 ±0.03 | -9.57 ±0.01 | | 0.74512 ±0.00005 | | 1.41951 ±0.00010 | | 0.00884 ±0.00010 |
| naphthalene | $C_{10}H_8$ |  | 0.0006 ±0.0004 | 217.96 ±0.03 | 80.27 ±0.02 | | (at 85°C) 0.9752 ±0.0002 | | (at 85°C) 1.5898 ±0.0002 | | (at 86°C) 0.0297 ±0.0002 |
| 2-methyl-5,6,7,8-tetrahydronaphthalene (β-methyltetralin) | $C_{11}H_{14}$ |  | 0.0046 ±0.0007 | 229.03 ±0.03 | -39.75 ±0.03 | 0.9537 ±0.0002 | 0.9500 ±0.0002 | 1.53572 ±0.00010 | 1.53365 ±0.00010 | 0.01668 ±0.00005 | 0.01662 ±0.00005 |
| 1-methyl-5,6,7,8-tetrahydronaphthalene (α-methyltetralin) | $C_{11}H_{14}$ |  | 0.0029 ±0.0004 | 234.35 ±0.05 | -22.90 ±0.03 | 0.9720 ±0.0002 | 0.9683 ±0.0002 | 1.54395 ±0.00010 | 1.54190 ±0.00010 | 0.01645 ±0.00005 | 0.01639 ±0.00005 |
| 2-methylnaphthalene (β-methylnaphthalene) | $C_{11}H_{10}$ |  | 0.0060 ±0.0003 | 241.14 ±0.05 | 34.44 ±0.02 | | (at 40°C) 0.99945 ±0.00005 | | (at 40°C) 1.60172 ±0.00010 | | (at 40°C) 0.02727 ±0.00010 |
| 1-methylnaphthalene (α-methylnaphthalene) | $C_{11}H_{10}$ |  | 0.0025 ±0.0011 | 244.78 ±0.10 | -30.77 ±0.06 | | 1.0163 ±0.0001 | | 1.61494 ±0.00010 | | 0.02547 ±0.00010 |

and 2-methylnaphthalene, and of their partly hydrogenated derivatives, 5,6,7,8-tetrahydronaphthalene, 1-methyl-5,6,7,8-tetrahydronaphthalene, and 2-methyl-5,6,7,8-tetrahydronaphthalene.

### Discussion

It may well be that the analysis of the kerosine and other fractions below the lubricant fraction, because they are less complex, will yield more information with less effort about the composition of the lubricant fraction than a direct attack on the lubricant fraction itself. Already valuable information along these lines has been obtained. Thus the presence in the kerosine fraction of tetrahydronaphthalene and its homologs is consistent with the previous finding that the lubricant fraction contains compounds in which both aromatic and naphthene rings occur in the same molecule. Similarly, it had been shown previously that in the lubricant fraction those molecules containing two aromatic rings were in large part ones in which these aromatic rings were linked together through two carbon atoms, as in naphthalene and its homologs.[8] As previously reported, these latter compounds have been isolated already from the kerosine fraction.


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[2] F. D. Rossini: *a, Proc. API* **19 [III]** 99 (1938); *b, Oil Gas J.* **37 [27]** 141 (1938); *c, Refiner Natural Gasoline Mfr.* **17 [11]** 557 (1938).

[3] B. J. Mair and A. J. Streiff, *J. Research Natl. Bur. Standards* **24**, 395 (NBS Research Paper 1289 (940).

[4] B. J. Mair and A. J. Streiff, *J. Research Natl. Bur. Standards* **27**, Oct. (1941).

[5] B. J. Mair, A. R. Glasgow, Jr., and F. D. Rossini, *J. Research Natl. Bur. Standards* **27**, 39 (NBS Research Paper 1402) (1941).

[6] B. J. Mair, A. R. Glasgow, Jr., and F. D. Rossini, *J. Research Natl. Bur. Standards* **26**, 591 (NBS Research Paper 1397) (1941).

[7] C. B. Willingham and F. D. Rossini, to be published in *J. Research Natl. Bur. Standards* (NBS Research Paper).

[8] B. J. Mair, C. B. Willingham, and A. J. Streiff, *J. Research Natl. Bur. Standards* **21**, 581 (NBS Research Paper 1145) (1938).

[9] B. J. Mair, and C. B. Willingham, *J. Research Natl. Bur. Standards* **17**, 923 (NBS Research Paper 954) (1936).


# Testing Heavy-Duty Motor Oils

*(Continued from page 137)*

using the torque wrench, and reproducing the exact pressure previously used. The same pressure should make the file scratch on the nut and bolt coincide. Unfortunately, all journals, especially after having been in use for some time, are not perfectly round. Where the journal is not round, the minimum and maximum diameter points should be determined. The journal should then be turned so that the lead strip is placed on the maximum diameter, and the above procedure carried out.

Summing up:

1. Be sure to use pure virgin lead, about 1/16 inch by .005 inch to .006 inch thick.

2. See that the strip is cut and placed so that it will not ride on either fillet.

3. After disassembling, examine the bearing to be sure the lead has left no impression on the bearing. On tight fits, this may happen and, therefore, the thickness of the lead would not be an accurate indication of the actual clearance.

4. If the journal is out of round by more than .002 inch a new crankshaft should be used.

### 36-Hour Varnish Test Procedure

Briefly, this procedure involves the use of a current model Chevrolet engine operated at 30 h.p. at 3150 r.p.m. for 36 hours, with the water out at 200° F. and the oil sump temperatures held at 280° F. The air-fuel ratio is held at 14.5 to 1. Full details of this test procedure will probably be made available by the S.A.E. Committee in the near future.


### Acknowledgment

The work covered in this paper was done by a number of cooperating laboratories working under the auspices of the Lubricants Division of the S.A.E. Standards Committee. Mr. E. W. Upham of Chrysler Corporation is Chairman.

The cooperating laboratories are listed below. The order of listing does not bear any relation to the laboratory numbers by which the laboratories are identified in the paper.

Atlantic Refining Company
Caterpillar Tractor Company
Continental Oil Company
E. I. du Pont de Nemours & Company
General Motors Corporation
Gulf Refining Company
Kendall Refining Company
Lubri-Zol Corporation
The Pure Oil Company
Quaker State Oil Refining Corporation
Shell Oil Company
Sinclair Refining Company
Socony-Vacuum Oil Company
Standard Oil Company of California
Standard Oil Development Company
Sun Oil Company
The Texas Company


### Reference Oils

The Reference Oils, (B-1, B-2, B-3, and B-4) were obtained from various sources by Dr. Floyd Miller and made available to the cooperating laboratories. The conventional oil inspection data, as supplied by Dr. Miller, is given below:

| OIL | B-1 | B-2 | B-3 | B-4 |
|---|---|---|---|---|
| Gravity | 24.3 | 30.1 | 29.1 | 22.5 |
| Flash °F | 425 | 475 | 480 | 415 |
| Fire °F | 475 | 435 | 450 | 455 |
| Vis/100° F. (SSU) | 584 | 411.4 | 434.5 | 527 |
| Vis/210° F. (SSU) | 60.2 | 60.4 | 60.2 | 55.5 |
| VI | 57 | 106 | 99 | 34 |
| Color (R) | 2¼ | 9¼ | 6 | 15 |
| Conradson Carbon (percent) | 0.29 | 0.11 | 0.46 | 0.039 |
| Pour °F | −15 | +15 | −15 | −25 |


**This paper was released by the Lubricants Division of the American Society of Automotive Engineers for presentation before the Division of Refining, American Petroleum Institute, at San Francisco November 3 to 7. It is subject to revision and its release was for stimulaton of written and oral discussion.**

# 1941 CFR Road Detonation Tests

## Further Experience with New Methods of Test

**Compiled from Report of the Cooperative Fuel Research Committee**

J. M. CAMPBELL, General Motors Research Laboratories
R. J. GREENSHIELDS, Shell Oil Company
W. M. HOLADAY, Socony-Vacuum Oil Company
C. B. VEAL, Society of Automotive Engineers

**THE cooperative road tests carried out during the past year have added considerable information and experience to that already existing on the subject of road detonation testing.**

**Extensive data were obtained on the fuel requirements of the 1940 and 1941 models of the three most popular cars. Corresponding data were obtained on the knocking characteristics of current gasolines representing the bulk of the sales volume in various parts of the United States.**

**On account of large variations in octane number requirements among different cars of the same make—due to differences in ignition timing, combustion-chamber deposit, and other causes—and on account of variations in commercial gasolines, it has been necessary to use statistical methods of analysis in the appraisal of fuel and engine relationships. These methods of analysis have been applied in a number of ways, and have proved very useful. For this reason, the continuance of cooperative activity in compiling current statistical information annually on fuels and car requirements is recommended.**

**This paper was presented to Division of Refining, before Twenty-second Annual Meeting of the American Petroleum Institute, at San Francisco, November 7, 1941.**

DURING the past year the Cooperative Fuel Research Committee has continued its investigation of the knocking characteristics of fuels and engines in actual service. The centralized road knock tests, made at San Bernardino more than a year ago [1] resulted in the development of various road-test procedures. At the same time the tests supplied data illustrative of certain new principles, which appeared to have useful application as a means of expressing some of the engineering relationships between fuels and engines. The data obtained at that time, however, although they were valuable and suggestive, were not considered sufficiently extensive to warrant unqualified recommendation of these procedures and methods of analysis without further experience with them in the hands of individual laboratories. Accordingly, the program carried out during the past year has been designed to test these procedures and methods of analysis, and to obtain more definite information with regard to their limitations as indicated by more extensive data.

The 1941 road detonation program was divided into sections, as follows:

1. Ignition-timing relationships.
2. Control fuel tests.
3. Procedure evaluation.
4. Survey of characteristics of commercial gasoline.
5. Survey of octane number requirements of 1940 and 1941 cars, with particular attention to Chevrolet, Ford, and Plymouth models.

The last section, relating to octane number requirements, was carried out in conjunction with the program of the Survey Division of the Cooperative Fuel Research Committee, and will not be considered in detail in this report.

### Ignition-Timing Relationships

In any given engine, ignition timing has a controlling influence on the knocking tendency, or octane number requirement. At the same time, ignition timing has an influence on power. Accordingly, when deciding on the most desirable ignition advance throughout the speed range, both power and detonation must be considered—usually resulting in a compromise between the retardation required for knock control and the advance necessary for power.

The so-called reference-fuel frameworks, [1] upon which ignition timing for maximum power and fractions thereof are superimposed, are a convenient means of expressing these ignition-timing relationships at wide-open throttle. Reference-fuel frameworks were developed for 1940 and 1941 models of Chevrolet, Ford, and Plymouth. Although space does not permit the inclusion of all of these data, repre-

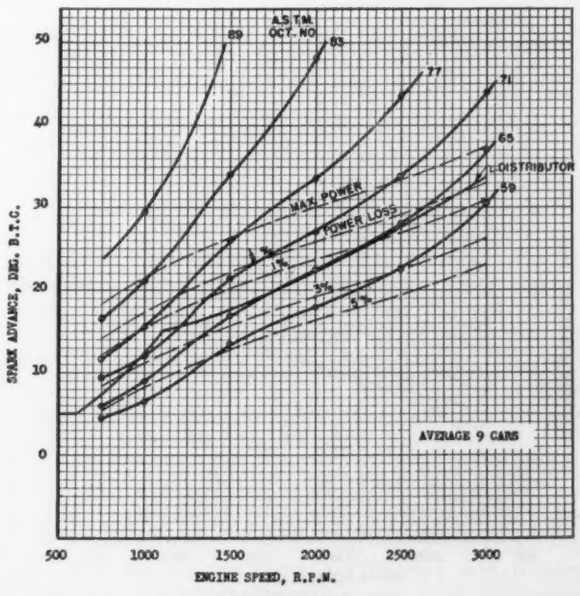


**FIGURE 1**

**Borderline Reference-Fuel Framework on 1941 Car "A" with Power Loss for Various Degrees of Spark Retard Superimposed.**

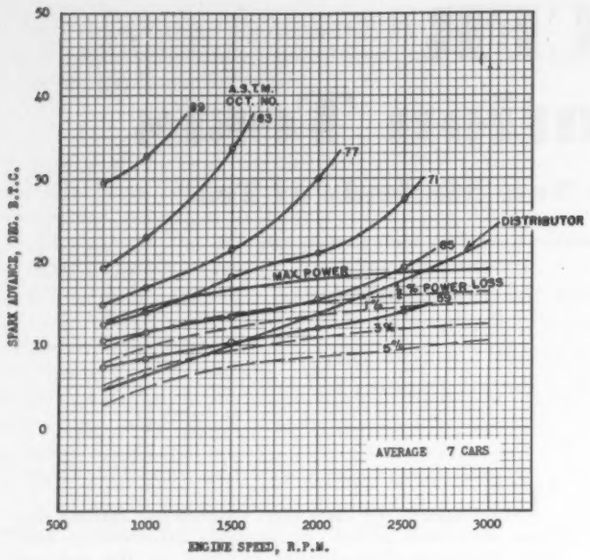


**FIGURE 2**

**Borderline Reference-Fuel Framework on 1941 Car "B" with Power Loss for Various Degrees of Spark Retard Superimposed.**

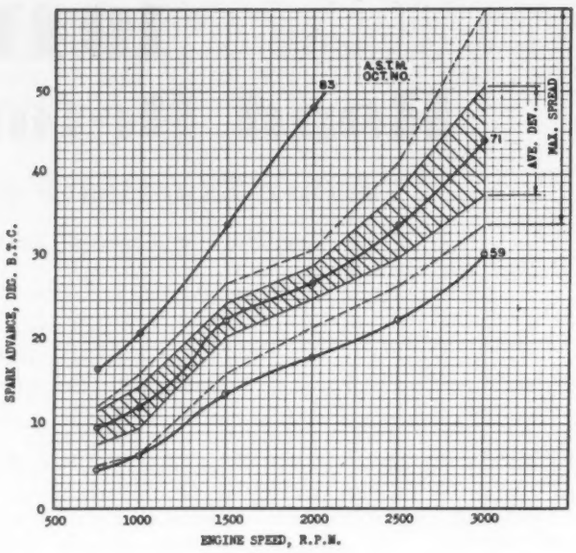


**FIGURE 4**

**Variation in Reference-Fuel Frameworks among 9 Units of 1941 Car "A."**

sentative average frameworks for the 1941 models are shown in Figures 1, 2, and 3.

Figures 1, 2, and 3 show the signal importance of ignition timing in controlling knock. For example, retarding the ignition 5° from the setting required for maximum power at 1,000 rpm (approximately 20 mph) resulted in a loss of about 1 percent in power and a reduction in the octane number requirement of from 6 to 10 octane numbers in these cars. The position of the curve representing the manufacturer's specification for distributor advance indicates that each of the three manufacturers has taken advantage of this principle by retarding the ignition relative to the setting for maximum power at the lower engine speeds. The position of the several different distributor curves represents the individual manufacturer's compromise of a number of factors, including power loss from retarded spark, octane number of available fuels, allowance for the effects of combustion-chamber deposit, allowance for deviations from proper ignition setting, and other elements peculiar to the design of each engine.

The most important limitation on the value of these reference-fuel frameworks is the variation from car to car of the same make. For example, Figure 4 illustrates the variations reported among nine different units of one make of car. This figure is based on the average value for each car, and the use of individual rather than average values for each car, of

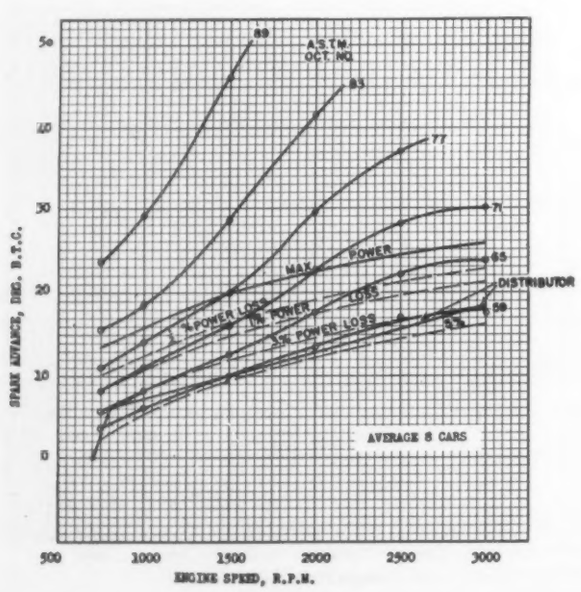


**FIGURE 3**

**Borderline Reference-Fuel Framework on 1941 Car "C" with Power Loss for Various Degrees of Spark Retard Superimposed.**

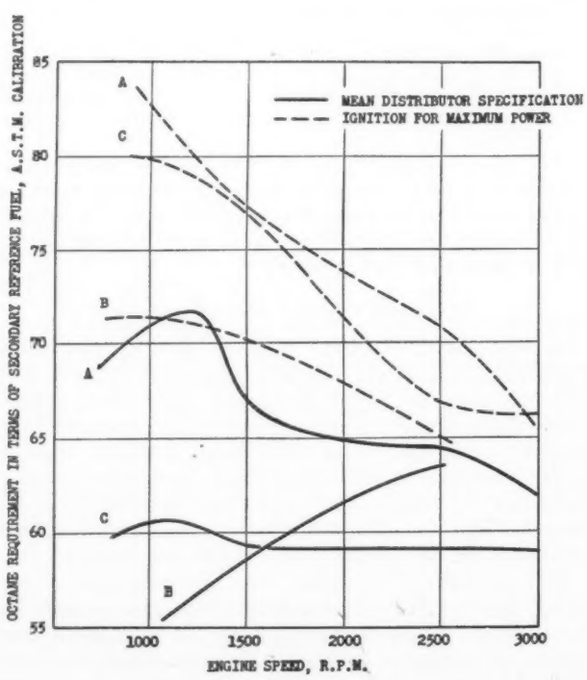


**FIGURE 5**

**Octane Number Requirements of 1941 Models of 3 Popular Low-Price Cars Based on Average of from 7 to 9 Units of Each Make.**

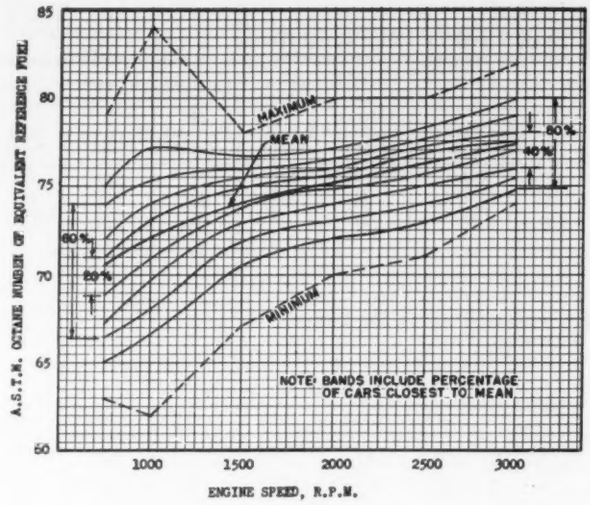


**FIGURE 6**
**Distribution of Road Octane Number Ratings of Control Fuel 41-A in 66 Cars.**

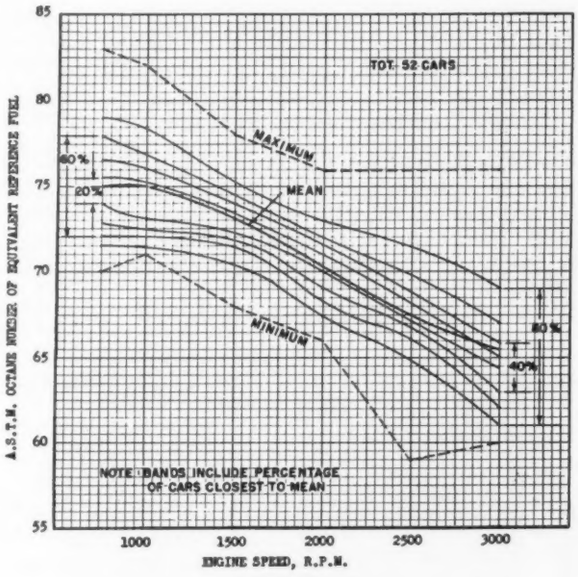


**FIGURE 7**
**Distribution of Road Octane Number Ratings of Control Fuel 41-B in 52 Cars.**

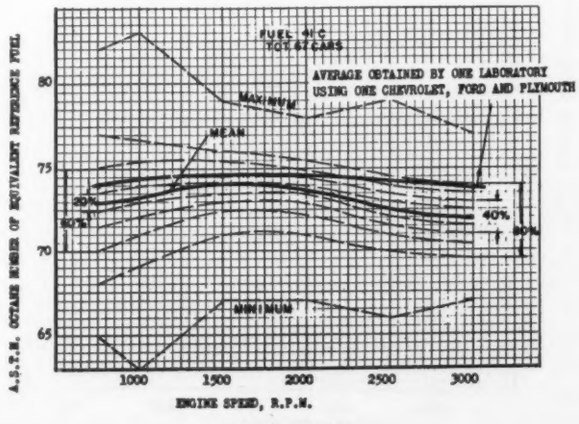


**FIGURE 8**
**Distribution of Road Octane Number Ratings of Control Fuel 41-C in 67 Cars.**

course, would result in an even greater spread. At high speed, the spread in the average deviation was about 12°, and at low speed about 4°. At either speed, this is equivalent of from 8 to 10 octane numbers.

This spread presumably is due to a number of causes, such as real differences between engines, errors due to inaccuracies in instrumentation for observing spark advance, and other sources of experimental error. Whatever the causes, these variations between cars have important significance in that they indicate the necessity for the use of statistical methods in the evaluation of the octane number requirements of any particular make of car, as found in customer service. The application of such statistical methods in "octane number requirement" surveys will be discussed further in a subsequent part of this report.

### Octane Number Requirements from Reference-Fuel Frameworks

The reference-fuel frameworks shown in Figures 1, 2, and 3, inasmuch as they are based on average data from a number of different units of each make, probably are the most representative evaluations available for each make of car. It is, therefore, of some interest to determine the average octane number requirement of each of these three makes, which represent more than 50 percent of total production for 1941. These are shown in Figure 5.

### Control Fuels

Four control fuels of widely different types were used by all of the cooperating laboratories in the 1941 road tests. A sufficient number of ratings was obtained to establish representative mean values of octane number for each fuel throughout the speed range. Such data make it possible to investigate the variations in ratings from car to car of the same make, and to compare ratings in different makes of cars. As one of the control fuels is a reference-fuel blend, certain deductions relative to experimental error can be made.

The control fuels were chosen to represent the following four different types of gasoline:

Paraffinic straight-run, containing tetraethyl lead.
Mid-Continent cracked (no lead).
Mixture Mid-Continent cracked, plus straight-run, and containing lead.
Secondary reference-fuel blend.

Average laboratory inspection data on these fuels are given in Table 1.

### Octane Number Vs. Speed Relationship

One of the outstanding developments of the San Bernardino road detonation tests was the concept of a relationship between engine speed and road octane number that can be used to characterize the behavior in service of different types of gasoline. This relationship is illustrated by the average road octane numbers, tabulated in Table 2, of the four control fuels used in the 1941 road tests.

It must be emphasized that the ratings in Table 2 are average values. The individual data show considerable variation in octane number at each engine speed. This appears due in part to differences between cars, and in part to other factors which might be classified as experimental error. The differences between various makes of cars—i.e., Chevrolet, Ford, and Plymouth — were not very consistent, however, and present information is not sufficient to indicate

**TABLE 1**
**Average Inspection Data on Four Control Fuels Used in 1941 Road Tests**

| Code Letter | ASTM Octane No. | Research Octane No. | ASTM Distillation, in °F | | | | |
|---|---|---|---|---|---|---|---|
| | | | Initial Boiling Point | 10 Percent Point | 50 Percent Point | 90 Percent Point | End Point |
| 41-A | 75.1 | 75.5 | 109 | 166 | 245 | 328 | 374 |
| 41-B | 69.4 | 79.7 | 93 | 126 | 247 | 370 | 414 |
| 41-C | 75.6 | 79.7 | 98 | 132 | 224 | 323 | 379 |
| 41-D | 75.9 | 78.6 | 117 | 159 | 199 | 248 | 335 |

**TABLE 2**
**Average Road Ratings of 1941 Control Fuels Expressed as ASTM Octane No. of Equivalent Secondary Reference Fuel**

| Code Letter | Engine Speed, RPM | | | | | |
|---|---|---|---|---|---|---|
| | 750 | 1,000 | 1,500 | 2,000 | 2,500 | 3,000 |
| 41-A | 70.7 | 72.0 | 74.1 | 75.2 | 76.3 | 77.9 |
| 41-B | 75.0 | 75.0 | 73.0 | 70.3 | 67.5 | 65.4 |
| 41-C | 73.0 | 73.2 | 74.3 | 73.7 | 72.6 | 72.3 |
| 41-D | 75.1 | 75.4 | 75.8 | 75.8 | 75.8 | 75.9 |

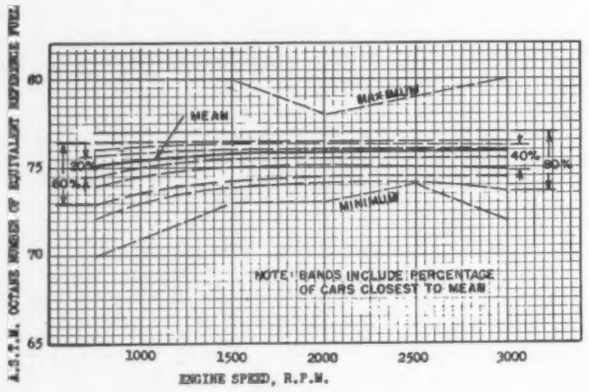


**FIGURE 9**
**Distribution of Road Octane Number Ratings of Control Fuel 41-D (Secondary Reference Fuel ASTM Octane No. 75.9) in 68 Cars.**

real and unmistakable differences between these different car makes. But, for whatever reason, variations in reported octane number ratings do exist; and it is necessary, therefore, to obtain a statistical representation of the octane number-speed relationship as it was actually reported for these tests. Such a representation is given in Figures 6, 7, 8, and 9. In these figures the distribution of more than 60 car ratings about the mean is shown. For example, Figure 8 shows that 40 percent of the ratings reported on 41-C at 1,500 rpm were between 73.0 and 74.7 octane number.

Under these circumstances it is obvious that erroneous conclusions can be reached by using a limited amount of data. It appears further that control fuels such as were used in these tests may have a useful place in future road-test work. As an example of the use of a control fuel to check the consistency of data obtained by an individual laboratory, the average road octane number data obtained by one laboratory on one Chevrolet, one Ford, and one Plymouth are shown in Figure 8. In this case the average for 3 cars, including 1 of each make, was within about 1 octane number of the grand average at speeds below 2,000 rpm. At higher speeds this divergence of the single laboratory average from the grand average increased to 1.7 octane numbers.

The conclusion to be reached from these data is that single ratings cannot be relied upon, owing to appreciable variations between runs in a given car and between different cars. At the same time, it cannot be emphasized too strongly that every precaution should be taken in obtaining the original road-test data to minimize the possibility of error in individual ratings.

## Procedure Evaluation

Evaluation of the three road-test procedures [1] developed at San Bernardino for obtaining road octane values involves two considerations: 1, comparison of ratings obtained by different methods on a given fuel; and, 2, comparative reproducibility of each method.

Figure 10 represents an analysis of the three meth-

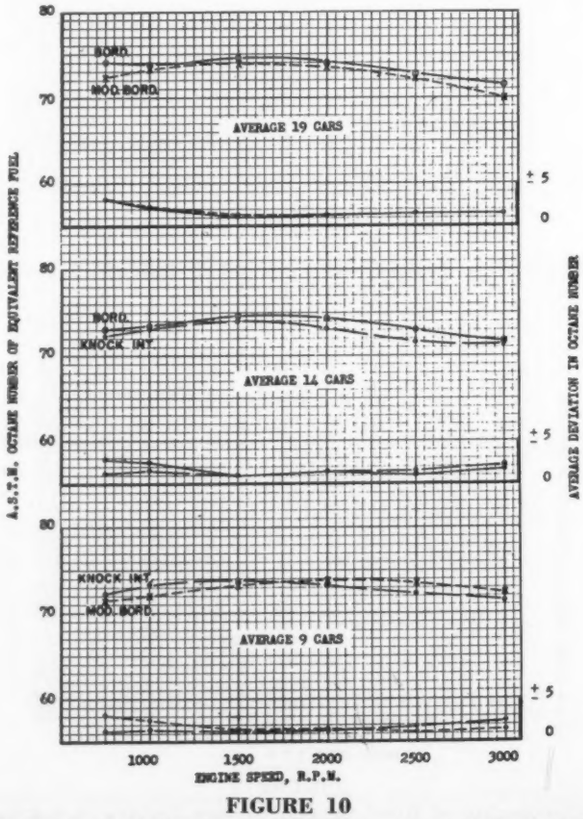


**FIGURE 10**
**Comparison of Testing Methods Using Control Fuel 41-C**

ods on this basis, using fuel 41-C as an example. In general, it appears that the three methods give approximately identical ratings for a given fuel. The differences found between different methods were of the order of one octane number—scarcely enough to be significant. The evaluation of any conclusion is conditioned further by the limited data available.

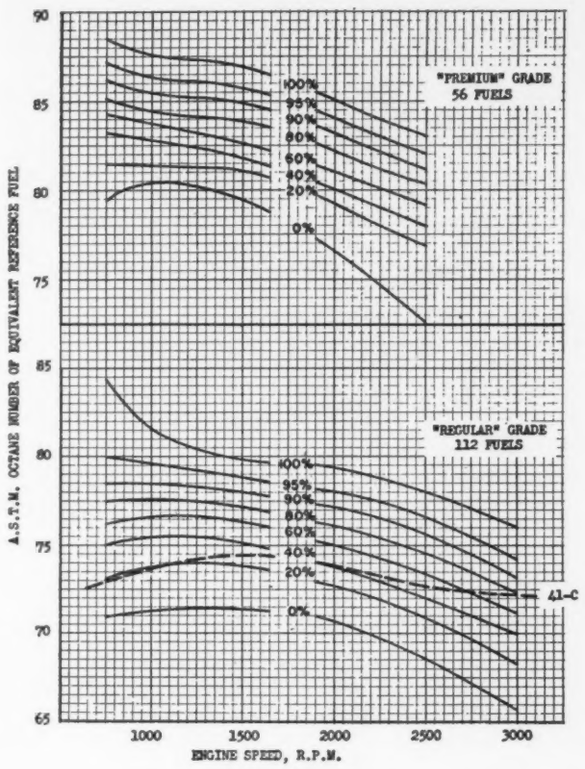


**FIGURE 11**
**Distribution of Road Octane Number Ratings of Commercial Fuels in All Cars.**

Reproducibility is expressed in Figure 10 by the average-deviation curves, which indicate little or no difference between the borderline and modified-borderline methods in this respect. At low engine speeds the knock-intensity method appears to have an advantage, and this was shown in the rating of all 4 control fuels below 1,000 rpm.

In general, it appears that the three procedures may be used interchangeably for obtaining road ratings. The choice of method depends somewhat upon its adaptability to the existing circumstances, and somewhat upon the individual preference of the operator. All three methods require a considerable amount of skill on the part of the observers.

### Commercial Gasoline Survey

To provide some statistics on the service characteristics of current commercial gasolines, each participating organization was asked to determine the octane number-speed characteristics of at least five "regular"-grade and two "premium"-grade gasolines. These fuels were to be selected to represent the major quantity of gasoline marketed in the area where each participant was located. By this means it was possible to obtain a reasonably representative sampling of gasolines marketed throughout the United States.

Data were reported on a total of 112 "regular" and 56 "premium" fuels, and the distribution of road octane number ratings in all cars is shown in Figure 11. The curves representing various fractions of the total were determined from a tabulation of octane ratings at six different speeds, and it should be pointed out that these curves bear no relation to the characteristics of the individual gasolines; i.e., the gasolines in the upper 10-percent bracket at 1,000 rpm are not necessarily the same as those in that bracket at 3,000 rpm.

This type of information has several applications. For example, it can be used in the evaluation of the characteristics of any given fuel, such as 41-C, the curve for which is superimposed on the statistical framework representing the "regular"-grade gasolines. Thus 41-C was a little below the average at 750 rpm, and a little above the average at 3,000 rpm.

By combining these statistics with corresponding octane number-requirement data for a given make of car, such as those shown in Figure 5, the probabilities of detonation in various speed ranges may be estimated. This information may be used also in conjunction with reference-fuel frameworks as a guide in the design of distributor characteristics that will conform with fuels currently available. When they are available, of course, corresponding data for a particular car make would be preferable for distributor design, and the complete CFR report contains separate figures representing the behavior of "regular" and "premium" gasolines in 1940 and 1941 models of Chevrolet, Ford, and Plymouth.

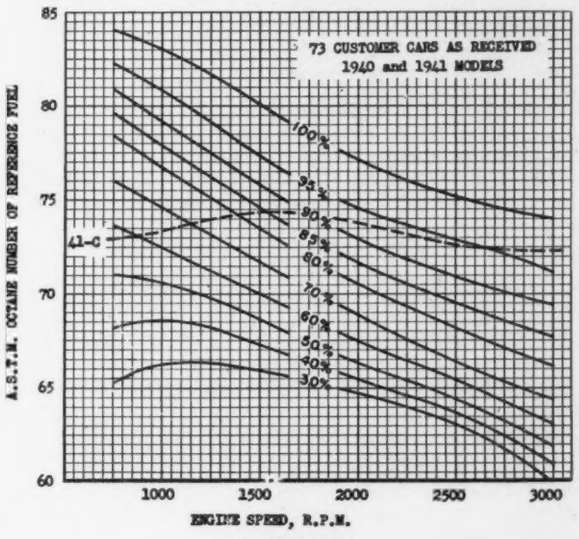


**FIGURE 12**
**Percentage of Cars Giving Borderline or No-knock on Reference-Fuel Blends.**

### Octane Number-Requirement Survey

In a preceding section of this report reference was made to a statistical method of expressing octane number requirements in a given make of car. For the information of the petroleum refiner, such an expression inclusive of several car makes would be even more desirable. To illustrate this type of information, Figure 12 was prepared from the octane number-requirement data obtained on 73 customer cars, as found in service, without adjustment. These cars included 24 Fords, 15 Chevrolets, 13 Plymouths, 7 Buicks, 5 Chryslers, and 9 cars of other make. Of these cars, 47 were tested again after adjustment of

the initial spark timing to the setting recommended by the manufacturer, and the results of this second survey are shown in Figure 13.

This type of information can be used as a guide in the anlysis of gasoline characteristics in relation to car requirements. For example, superimposing the average road rating of gasoline 41-C on the data in Figure 12 visually presents an estimate of the percentage of cars that can be operated on this fuel without knock. Thus at 750 rpm less than 50 percent, and at 3,000 rpm less than 5 percent, of the cars will knock on this fuel. A similar analysis can be made

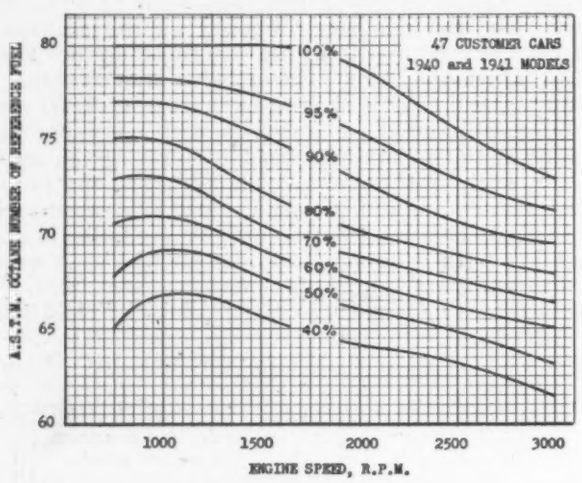


**FIGURE 13**

**Percentage of Cars Giving Borderline or No-knock on Reference-Fuel Blends after Adjustment of Initial Spark Timing in Accordance with Manufacturer's Specifications.**

for each car make, provided sufficient data are available.

Combining the fuel-survey data illustrated in Figure 11 with octane number-requirement survey data of the type illustrated in Figure 12 graphically presents the statistical relationship, for freedom from knock, between current fuel characteristics and car requirements. This relationship is shown in Figure 14. Appraised by this comparison, the average "regular"-grade fuel will be satisfactory—operate without knock—in more than 75 percent of these cars at 1,000 rpm (approximately 20 mph), and will be equally satisfactory in more than 90 percent of the cars at 3,000 rpm (approximately 60 mph).

The validity of such conclusions depends, of course, upon the availability of sufficiently representative data; and for this purpose the pooling of information from different laboratories is very desirable.

## Acknowledgment

The CFR committee is indebted to the 23 organizations that contributed data to this project, and to the Analysis Group,* the members of which have given generously of their time and energy to the task of tabulating and analyzing the very considerable quantity of data involved.

## Participating Organizations—1941 Road Detonation Tests

The Atlantic Refining Company, Chrysler Corporation, Cities Service Oil Company, Ethyl Gasoline Corporation, General Motors Corporation, General Petroleum Corporation, Gulf Research and Develop-

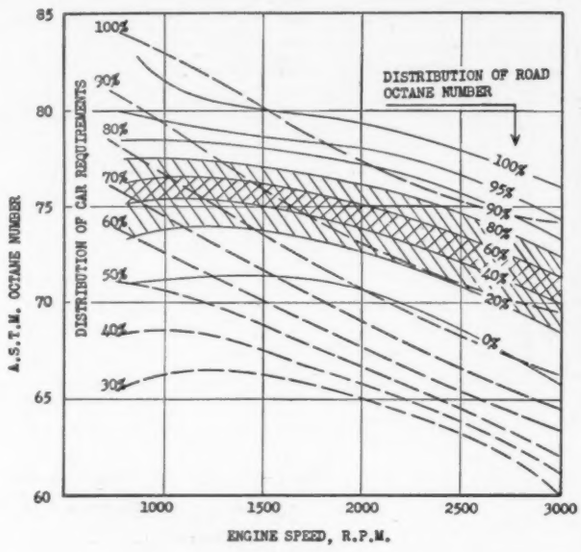


**FIGURE 14**

**Relationship between Road Octane Number of Commercial "Regular"-Grade Gasolines and Car Requirements Shown in Figure 12.**

ment Company, Holley Carburetor Company, National Bureau of Standards, Phillips Petroleum Company, The Pure Oil Company, Shell Oil Company, Inc., Sinclair Refining Company, Socony-Vacuum Oil Company, Inc., Standard Oil Company of California, Standard Oil Company (Indiana), The Standard Oil Company (Ohio), Standard Oil Development Company, Sun Oil Company, The Texas Company, Tide Water Associated Oil Company (Bayonne), Tide Water Associated Oil Company (California) †, Union Oil Company, and Universal Oil Products Company.

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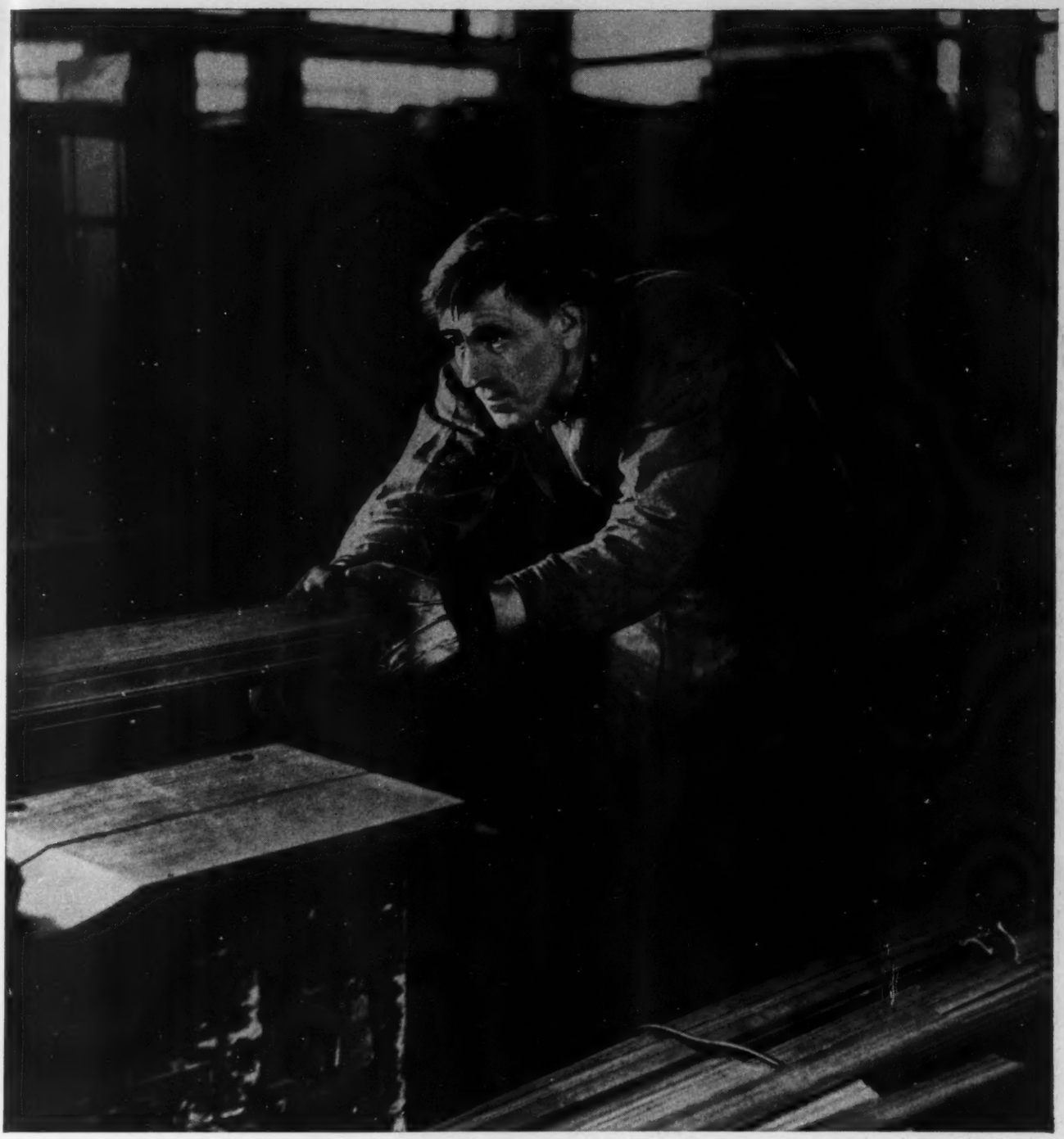
[1] *Proc. API* **22M [III]** 119 (1941); *SAE Journal* **48 [5]** 193 (1941).

† No data submitted.

* The personnel of the Analysis Group was: R. J. Greenshields (leader), Shell Oil Co., Inc.; M. J. Anderson, Ethyl Gasoline Corp.; H. W. Best, Yale University; K. Boldt, The Pure Oil Co.; W. E. Drinkard, Chrysler Corp.; J. G. Moxey, Jr., Sun Oil Co.; C. H. Van Hartesveldt, The Atlantic Refining Co.; C. B. Veal, Society of Automotive Engineers; and T. A. Weir, Socony-Vacuum Oil Co., Inc.



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# Petroleum Demand Continues Heavy; Exports Larger

By L. J. LOGAN

DOMESTIC demand for petroleum products has continued sharply higher than last year, and despite recent cutting off of shipments to the important customer, Japan, exports now are running above year-ago levels for the first time since the German invasion of France and the Low Countries. Consequently, total demand, as well as domestic consumption, now exceeds the trend of 1940 by an extraordinary margin.

For this year as a whole, total demand has been approximately 8 percent greater than last year, but in August the increase was 14.4 percent. Domestic demand for all petroleum products was 15.3 percent greater than in August of last year, and total exports showed an increase of 5.7 percent, as shipments of refined products were up 22.5 percent, although those of crude oil were off 21.5 percent.

These are the latest available statistics on demand, but subsequent months have brought continuance of record-breaking requirements, although it has been anticipated that increasing defense production might interfere with "business as usual" in the fourth quarter of the year and hold down the year-to-year gains to around 12 percent for domestic demand and 10 percent for total demand. Similar gains have been forecast, also, for the first quarter of 1942.

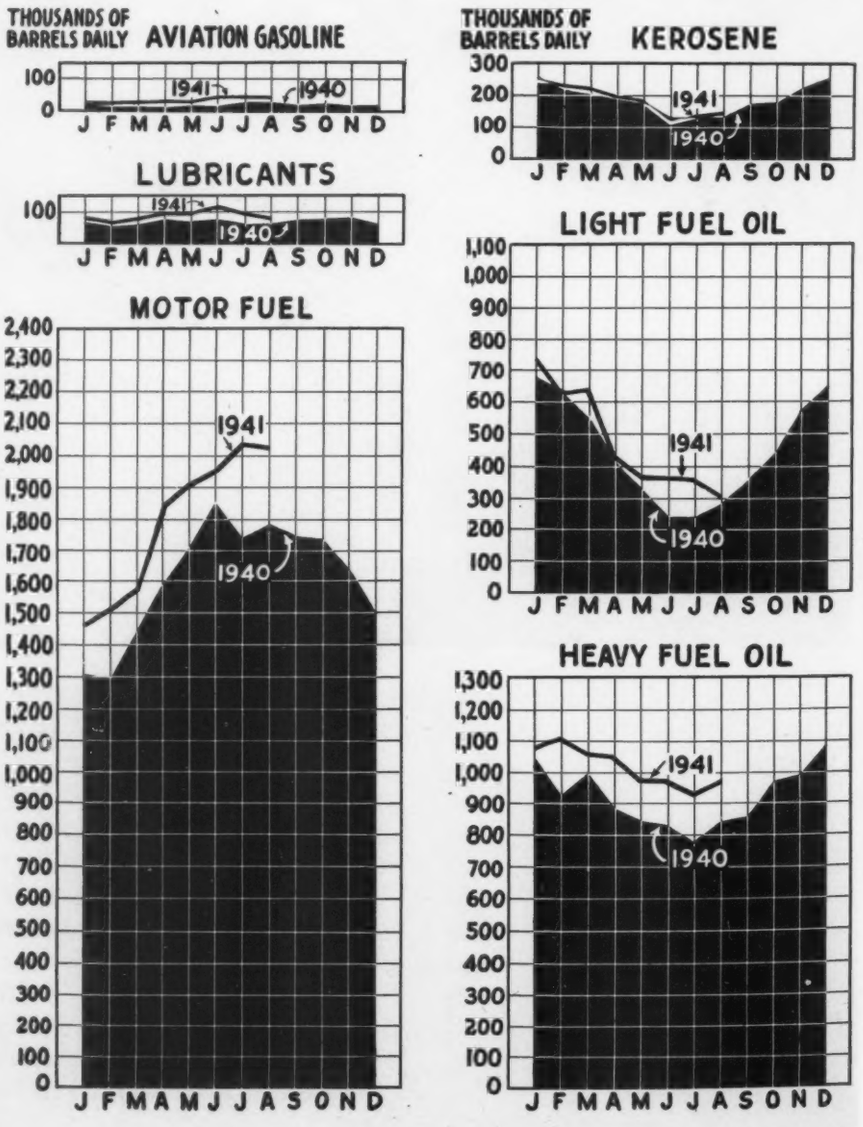
As indicated in the accompanying table, total demand normally shows changes closely in line with those for motor fuel, and for September the Bureau of Mines predicted a 10 percent gain over September of last year in domestic use of motor fuel and an 11.1 percent increase in total demand for that product, including higher exports. For October the bureau foresaw an 11 percent increase in domestic use and practically the same exports as a year previously. For November the agency has forecast that the domestic demand for motor fuel would be 13 percent higher than the relatively low actual demand in November, 1940, and its estimate for exports of that product was 2,500,000 barrels, against actual shipments of 2,205,000 barrels in November of last year.

While demand for all petroleum products has been running about 15 percent above a year ago, gains for the individual products have varied considerably.

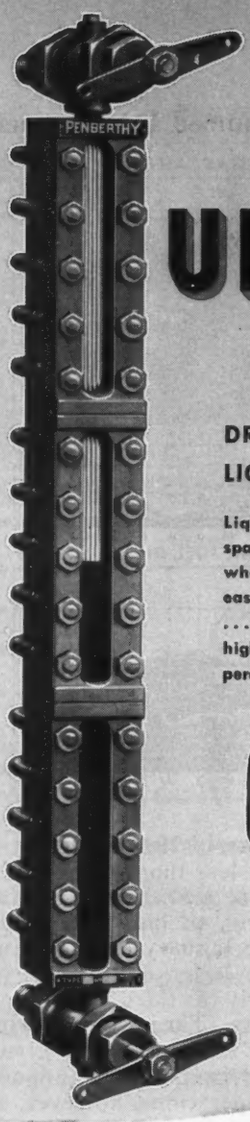
Total motor fuel demand was 14.3 percent greater in August, 1941, than in August, 1940, with domestic use up 13.7 percent and

**Domestic Consumption of Oils Sharply Higher This Year**

Based on Bureau of Mines data, charts show daily average domestic demand for principal petroleum products, by months, in 1940 and 1941.



# QUALITY UNCOMPROMISED

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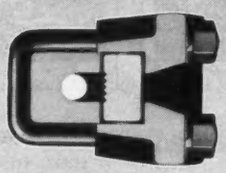

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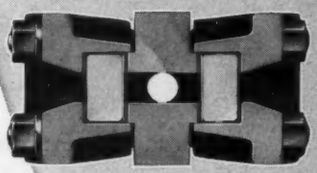

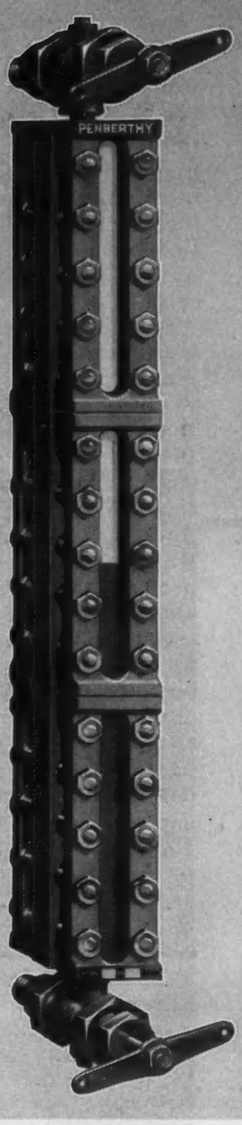


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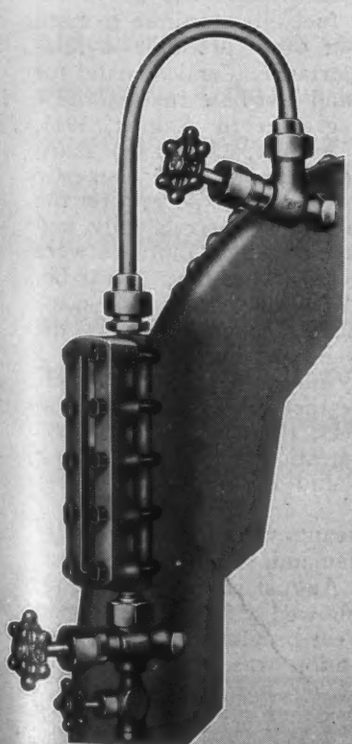

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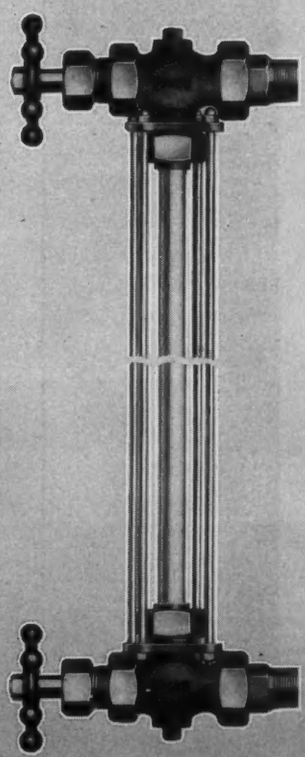

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exports 29.4 percent higher in totaling 2,700,000 barrels. For the first 8 months of 1941, total gasoline demand showed a 10.8 percent increase, with domestic consumption 12.2 percent larger and exports off 19.7 percent to 13,530,000 barrels.

Aviation gasoline requirements were more than twice as great in August, 1941, as one year previously, with domestic consumption nearly four times as large (41,000 barrels daily against 12,000). Exports meanwhile were one third larger. For the first 8 months, total demand for aviation gasoline was up one third, with domestic use two thirds higher and exports about unchanged.

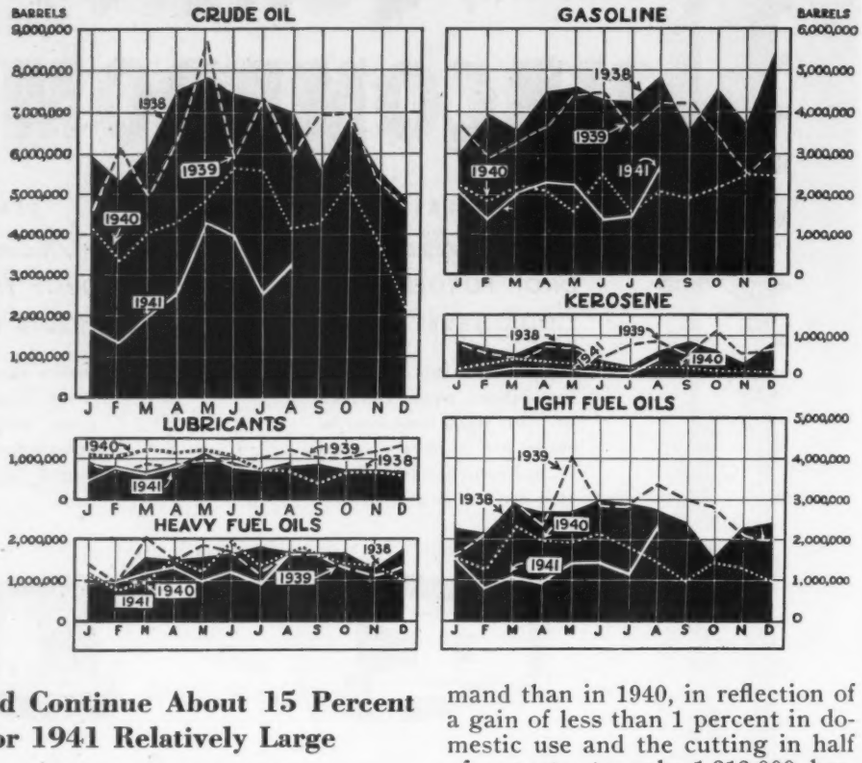
Kerosene demand in total was up 11.6 percent in August, in reflection of gains of 8.1 percent in domestic consumption and almost a doubling of exports. For this year as a whole, however, kerosene has been in slightly smaller demand than in 1940, in reflection of a gain of less than 1 percent in domestic use and the cutting in half of exports, to only 1,312,000 barrels from January through August, with the latter month accounting for nearly a third of the year's shipments. The poor showing of kerosene has not been of great significance from the standpoint of overall operations, however, as the volume of that product now marketed is only 1/10 of the volume of gasoline sold.

Light fuel oils continue to keep abreast of other products in relative importance. Total demand for gas oil and distillate fuel was 21.7 percent greater in August, 1941, than in August, 1940, as a sharp gain in exports occurred. Domestic demand was up 15.6 percent for the month at 312,000 barrels daily, and shipments to other countries were 56.6 percent larger than a year before at 2,300,000 barrels, those exports having been close to the quantity of gasoline exported.

Heavy fuel oils were in 13.1 percent greater total demand in August, 1941, than in August, 1940, with domestic consumption up 14.8 percent and exports 11.8 percent lower.

Lubricants were in exceptionally large demand, domestic and export, in August, and total requirements showed a 25.8 percent gain over a year previously, as domestic consumption was up 26.6 percent to 2,562,000 barrels, while shipments to other countries were 23.8 percent larger at 900,000 barrels.

## Monthly Exports of Oils Show Pronounced Improvement




## Total and Domestic Oil Demand Continue About 15 Percent Above Year Ago; Gains for 1941 Relatively Large

(Figures indicate barrels, and are from Bureau of Mines)

| | AUGUST | | | FIRST 8 MONTHS | | |
|---|---|---|---|---|---|---|
| | 1940 | 1941 | Percent Change | 1940 | 1941 | Percent Change |
| **SUMMARY—** | | | | | | |
| **Total Demand** | 121,130,000 | 138,614,000 | + 14.4 | 951,690,000 | 1,025,305,000 | + 7.7 |
| Daily Average | 3,907,000 | 4,471,000 | + 14.4 | 3,900,000 | 4,219,000 | + 8.2 |
| **Exports:** | | | | | | |
| Crude Petroleum | 4,170,000 | 3,275,000 | — 21.5 | 36,192,000 | 22,719,000 | — 37.2 |
| Refined Products | 6,760,000 | 8,284,000 | + 22.5 | 56,695,000 | 43,370,000 | — 23.5 |
| Total Exports | 10,930,000 | 11,559,000 | + 5.7 | 92,887,000 | 66,089,000 | — 28.8 |
| **Domestic Demand:** | | | | | | |
| Total Domestic Demand | 110,200,000 | 127,055,000 | + 15.3 | 858,803,000 | 959,216,000 | + 11.7 |
| Daily Average | 3,555,000 | 4,099,000 | + 15.3 | 3,520,000 | 3,947,000 | + 12.1 |
| **TOTAL DEMAND FOR PRODUCTS** | | | | | | |
| **MOTOR FUELS:** | | | | | | |
| Domestic | 55,346,000 | 62,944,000 | + 13.7 | 387,833,000 | 434,963,000 | + 12.2 |
| Exports | 2,087,000 | 2,700,000 | + 29.4 | 16,863,000 | 13,530,000 | — 19.7 |
| Total | 57,433,000 | 65,644,000 | + 14.3 | 404,636,000 | 448,493,000 | + 10.8 |
| **Aviation Gasoline:** | | | | | | |
| Domestic | 371,000 | 1,267,000 | +241.5 | 4,144,000 | 6,705,000 | + 61.8 |
| Exports | 569,000 | 777,000 | + 36.5 | 3,115,000 | 3,044,000 | — 2.3 |
| Total | 940,000 | 2,044,000 | +117.4 | 7,259,000 | 9,749,000 | + 34.3 |
| **Kerosene:** | | | | | | |
| Domestic | 4,114,000 | 4,449,000 | + 8.1 | 43,419,000 | 43,764,000 | + 0.8 |
| Exports | 230,000 | 400,000 | + 73.9 | 2,748,000 | 1,312,000 | — 52.3 |
| Total | 4,344,000 | 4,849,000 | + 11.6 | 46,167,000 | 45,076,000 | — 2.4 |
| **Gas & Oil Distillate Fuels:** | | | | | | |
| Domestic | 8,362,000 | [1]9,667,000 | + 15.6 | 100,472,000 | 113,243,000 | + 12.7 |
| Exports | 1,469,000 | 2,300,000 | + 56.6 | 14,632,000 | 10,290,000 | — 29.7 |
| Total | 9,831,000 | 11,967,000 | + 21.7 | 115,104,000 | 123,533,000 | + 7.3 |
| **Residual Fuel Oils:** | | | | | | |
| Domestic | 26,267,000 | [2]30,169,000 | + 14.8 | 219,314,000 | 244,957,000 | + 11.7 |
| Exports | 1,815,000 | 1,600,000 | — 11.8 | 10,912,000 | 9,327,000 | — 14.5 |
| Total | 28,082,000 | 31,769,000 | + 13.1 | 230,226,000 | 254,284,000 | + 10.4 |
| **Lubricants:** | | | | | | |
| Domestic | 2,024,000 | 2,562,000 | + 26.6 | 15,701,000 | 20,679,000 | + 31.7 |
| Exports | 727,000 | 900,000 | + 23.8 | 8,227,000 | 6,340,000 | — 22.9 |
| Total | 2,751,000 | 3,462,000 | + 25.8 | 23,928,000 | 27,019,000 | + 12.9 |
| **Wax** (thousands of pounds): | | | | | | |
| Domestic | 41,897 | 54,027 | + 28.9 | 219,115 | 345,146 | + 57.5 |
| Exports | 8,968 | 16,716 | + 86.4 | 147,766 | 112,552 | — 23.8 |
| Total | 50,865 | 70,743 | + 39.1 | 366,881 | 457,698 | + 24.8 |
| **Coke** (short tons): | | | | | | |
| Domestic | 117,400 | 102,700 | — 12.5 | 907,100 | 979,700 | + 8.0 |
| Exports | 36,200 | 29,300 | — 19.1 | 173,300 | 172,500 | — 0.5 |
| Total | 153,600 | 132,000 | — 14.1 | 1,080,400 | 1,152,200 | + 6.6 |
| **Asphalt** (short tons): | | | | | | |
| Domestic | 672,400 | 840,000 | + 24.9 | 3,215,900 | 4,050,600 | + 25.9 |
| Exports | 32,000 | 23,200 | — 27.5 | 214,700 | 164,200 | — 23.5 |
| Total | 704,400 | 863,200 | + 22.5 | 3,430,600 | 4,214,800 | + 22.9 |
| **Road Oil:** | | | | | | |
| Domestic Demand | 1,553,000 | 1,694,000 | + 9.1 | 5,569,000 | 6,089,000 | + 9.3 |
| **Miscellaneous:** | | | | | | |
| Domestic | 242,000 | 280,000 | + 15.7 | 1,357,000 | 2,283,000 | + 68.2 |
| Exports | 43,000 | 50,000 | + 16.3 | 739,000 | 403,000 | + 45.5 |
| Total | 285,000 | 330,000 | + 15.8 | 2,096,000 | 2,686,000 | + 28.1 |

[1] Includes 594,00 barrels Diesel bunker oil. [2] Includes 1,956,000 barrels bunker fuel oil

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**Evidence? Cooper-Bessemer horizontal engines and compressors in production and transmission plants everywhere. Cooper-Bessemer vertical gas and diesel engines driving generators, charging pumps and pipeline pumps in refineries throughout the country. Cooper-Bessemer angle and v-angle compressor units in many of the largest recycling plants, refineries and transmission stations.**

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**Oil Company Earnings for 1941 Likely to be Comparable with Those in Good Years, 1926, 1928, 1929, and 1937**

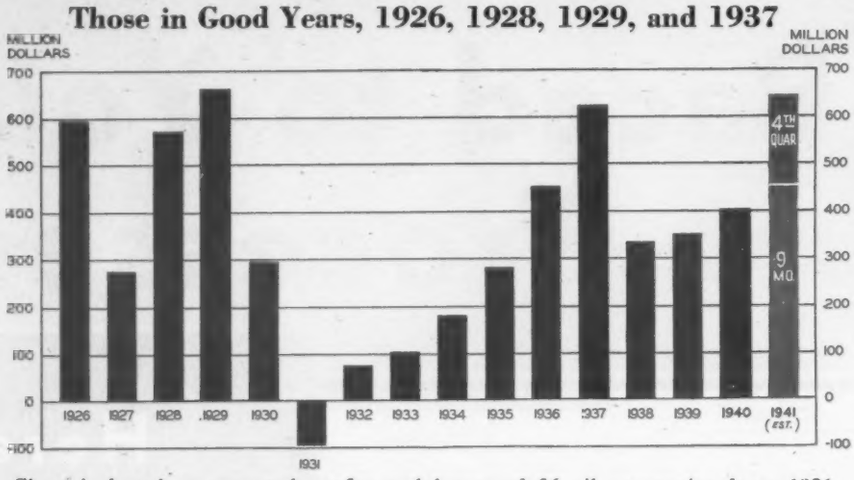


Chart is based on reported profits and losses of 36 oil companies from 1926 through 1940 and on indications for 1941 as discussed in accompanying text.

# Earnings Favorable as Oil Use Expands While Prices Improve

THROUGH benefit of record-breaking demand for petroleum products and improved prices of crude oil and its derivatives, oil company earnings for 1941 promise to be closely comparable with those for 1937 and 1929, hitherto the most profitable years in the history of the industry.

As indicated on an accompanying chart, it appears that 1941 earnings may be somewhat better than those of 1937 and almost as good as those of 1929.

The charted estimate is based on actual results in the first 9 months for 22 companies that are well representative of the industry and on the assumption that earnings in the final quarter will be approximately the same as those in the third quarter, with volumes of business closely comparable and prices about the same or slightly better.

(Gasoline sales normally decrease somewhat in the fourth quarter, but the season brings at least partially compensating increases in sales of heating oils, kerosene, and heavy fuel oils and this year, there probably will be a less pronounced dropping off in gasoline business, as the third quarter had two months of curtailed deliveries to service stations on the East Coast, while the fourth quarter had less than a month of such curtailment before restrictions were lifted.)

For the first 9 months of 1941, the earnings of oil companies approached but did not equal the profits in the corresponding months of 1937. As shown in the accompanying table and one of the charts presented herewith, 22 companies in the aggregate earned 83.7 percent as much from January through September of 1941 as in those months of 1937. But results for 1941 became progressively better as the year advanced, and for the September quarter, the 22 companies earned 92.8 percent as much as in the corresponding period of 1937. For the fourth quarter of 1941, even better earnings than in the final period of 1937 are indicated, inasmuch as late 1937 brought the beginning of the business recession of 1937-1938 and a weakening of prices of gasoline and other petroleum products.

(In July, August, and September of 1937, regular grade gasoline at Oklahoma refineries was priced at 6.06, 6.06, and 5.91 cents a gallon, respectively, and for October, November, and December, the price declined to 5.69, 5.10, and 4.86 cents; while dealer's net price in 50 cities went from 10.51, 10.66, and 10.66 cents in July, August, and September, to 10.63, 10.58, and 10.30 cents in October, November and December. In contrast, gasoline prices slightly improved in July, August, and September, 1941, and they are holding steady in the final quarter.)

This year's record of earnings has been one of progressive improvement, in reflection of extraordinary demand for crude oil and refined products and resultant large volumes of business and also in reflection of improvement in prices of both crude and refined oils.

For the first quarter, earnings were about one fourth lower in 1941 than in 1940. In the second quarter, there was a year-to-year improvement of about one third, but for the first 6 months of 1941 as a whole, earnings did not quite equal those of the initial half of 1940. Improvement continued in the third quarter of this year, and as shown herewith, 22 companies, representative of the industry, earned more than twice as much as in the unsatisfactory September quarter of last year, when markets were weakening. Through benefit of the exceptionally good results in the third quarter, the 22 companies showed for the first 9 months of this year 36.8 percent more net income than in the corresponding months last year. For the fourth quarter, improvement over 1940 is even more pronounced, as earnings were exceptionally poor in the closing months of last year, because prices of gasoline and other products continued downward during

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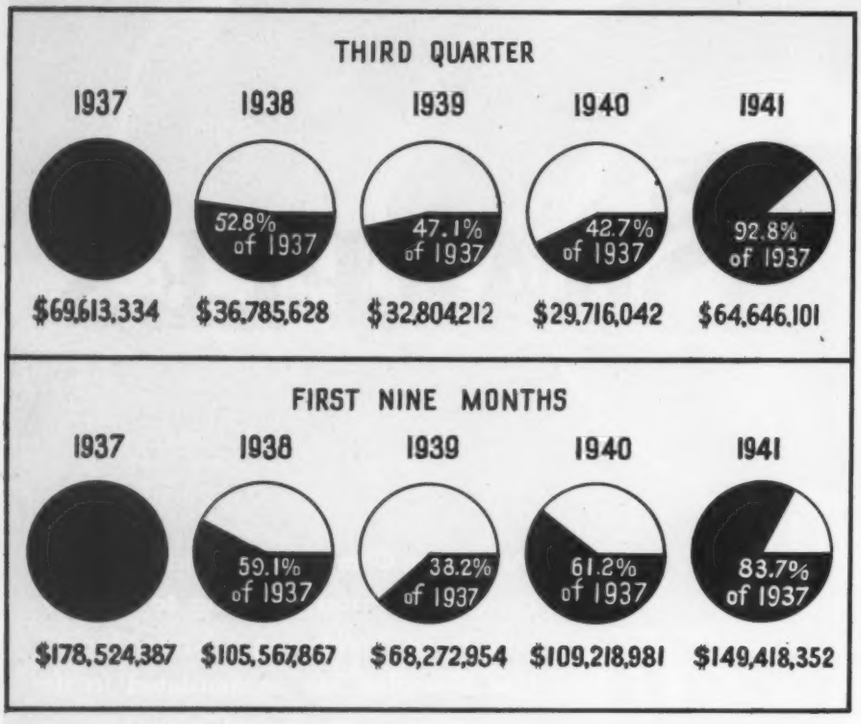
## Profits of 22 Oil Companies for Third Quarter and First 9 Months Compare Favorably with Those in 1937




that period and did not rally until early 1941. The $149,418,352 earned by the 22 companies in the first 9 months of 1941 was 11 percent more than the $134,106,760 that they earned in the full year 1940.

In order to show how earnings of the industry in 1941 will compare with those in earlier years, there is included herewith the chart indicating actually reported aggregate profits from 1926 through 1940, inclusive, for 36 companies that constitute a large part of the industry; and the estimate for 1941 is based on results in the first 9 months for 22 representative companies and on fairly clear prospects for the final quarter. The 22 companies earned 11.4 percent more in the first 9 months of 1941 than in the whole year 1940, and if the 36 companies did equally as well, their aggregate net income for the first 9 months was as shown on the chart. The 22 companies, moreover, earned 43.3 percent of their 9 months' profit in the third quarter, and it is here assumed that the 36 companies had a similar experience. Finally, it is assumed that such third quarter earnings for the 36 companies will be approximately duplicated in the fourth quarter, as shown on the chart.

The charted estimate for 1941 will prove correct, therefore, only in so far as results for the industry as a whole conform with those of the 22 companies and in so far as the fourth quarter brings a repetition of third quarter earnings.

For the immediate future, there is in prospect a continuation of favorable earnings for oil companies, as further expansion of volumes of business is indicated, while prices of crude and products are strong and would improve if allowed by the government to do so. However, favorable demand and prices are partially offset by higher taxes, increased costs of materials, and larger wages and salaries; and unless the government henceforth permits higher oil prices in compensation for additional increases of costs in the industry, earnings must diminish; although men of the industry contend that favorable prices are especially essential now, in order to keep oil field discoveries abreast of the heavy withdrawals that are being made from established reservoirs.

## September Quarter Brings Further Improvement in Earnings, and 22 Oil Companies Report One Third More Profit for First 9 Months Than They Did Last Year

After all deductions, including interest, depreciation, depletion, amortization, federal taxes, minority interest, etc.

| COMPANY | QUARTER ENDED SEPTEMBER 30 | | | | | | FIRST NINE MONTHS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1937 | 1938 | 1939 | 1940 | 1941 | Percent Change 1940-1941 | 1937 | 1938 | 1939 | 1940 | 1941 | Percent Change 1940-1941 |
| Amerada Corp. | $ 603,773 | $ 473,825 | $ 108,636 | $ 439,513 | $ 717,625 | + 63.3 | $ 1,673,880 | $ 1,356,886 | $ 783,625 | $ 1,324,877 | $ 1,817,911 | + 37.2 |
| Atlantic Refining Co. | 4,049,244 | 1,068,673 | 1,774,539 | 1,295,628 | [4]4,103,110 | + 216.7 | 7,486,000 | 3,930,407 | 3,124,448 | 6,560,394 | 9,164,653 | + 39.7 |
| Barnsdall Oil Corp. | [3]976,364 | 912,290 | 204,427 | [2]560,609 | [3]3,143,880 | + 460.8 | [3]2,232,694 | 2,602,329 | 1,262,466 | 1,650,737 | 4,453,985 | + 169.8 |
| Continental Oil Co. | 3,730,045 | 2,706,698 | 1,528,562 | 911,345 | 4,733,138 | + 419.4 | 11,614,575 | 5,793,406 | 4,065,842 | 3,299,631 | 8,590,802 | + 160.3 |
| Houston Oil Co. & Houston P. L. Co. | 328,411 | [1]449,923 | 91,459 | 63,129 | 204,340 | + 223.7 | 1,253,824 | [1]1,296,371 | 618,967 | 637,738 | 885,571 | + 38.9 |
| Lion Oil Refining Co. | 489,004 | 389,532 | 165,760 | 598,662 | [3]304,726 | — 49.1 | [1]1,020,268 | [1]984,688 | [1]380,938 | [1]977,538 | 745,063 | — 23.8 |
| Ohio Oil Co. | 3,592,654 | 1,252,346 | 262,971 | 2,495,494 | [3]3,027,473 | + 21.3 | 10,315,011 | 3,935,862 | 120,412 | 7,153,891 | 7,804,288 | + 9.1 |
| Panhandle Producing & Refining Co. | [1]91,211 | [1]27,566 | *2,739 | *21,604 | 110,977 | ..... | [1]227,887 | 143,820 | 16,861 | *38,490 | 200,811 | ..... |
| Phillips Petroleum Co. | 7,134,638 | 3,886,816 | 1,704,988 | 2,400,335 | 4,325,918 | + 80.2 | 19,813,719 | 9,471,956 | 5,479,057 | 8,778,533 | 12,562,598 | + 43.1 |
| Plymouth Oil Co. | 750,974 | 665,886 | 500,662 | 232,368 | 387,747 | + 66.9 | 2,113,970 | 1,994,006 | 1,673,366 | 1,231,188 | 1,015,924 | — 17.5 |
| Quaker State Oil Refining Corp. | 172,731 | 572,283 | 536,757 | 85,686 | 591,607 | + 590.4 | 1,052,291 | 413,904 | 1,091,547 | 244,931 | 1,508,454 | + 515.9 |
| Seaboard Oil Co. of Deleware | 552,164 | 466,422 | 384,157 | 129,367 | 296,427 | + 129.1 | 1,782,382 | 1,360,308 | 1,169,588 | 891,859 | 878,023 | — 1.6 |
| Shell Union Oil Corp. | 7,503,291 | 3,534,066 | 4,548,236 | 3,165,000 | 6,656,000 | + 110.3 | 15,984,218 | 9,364,493 | 6,710,658 | 12,615,195 | 14,486,000 | + 14.8 |
| Skelly Oil Co. | 1,911,022 | 695,180 | 609,327 | 706,943 | 1,358,149 | + 92.1 | 5,346,940 | 1,973,422 | 1,366,245 | 2,251,905 | 4,027,895 | + 78.9 |
| Standard Oil Co. of California | 13,355,627 | 8,480,446 | 5,523,295 | 6,360,675 | 11,843,132 | + 86.2 | 31,135,817 | 23,893,880 | 12,640,899 | 16,730,170 | 24,613,199 | + 47.1 |
| Sunray Oil Corp. | 302,430 | 105,932 | 68,637 | 70,782 | 317,758 | + 348.9 | 844,490 | 532,586 | 418,050 | 323,002 | 623,486 | + 93 0 |
| Superior Oil Corp. | 171,418 | 97,872 | *30,184 | 48,073 | 26,796 | — 44.3 | 314,197 | 292,817 | 21,684 | 125,056 | [4]144,821 | + 15.8 |
| Texas Pacific Coal & Oil Co. | [1]260,042 | [1]279,794 | [1]201,990 | [1]55,286 | 300,626 | + 443.8 | [1]715,548 | [1]780,542 | [1]617,802 | [1]348,126 | 770,131 | + 121.2 |
| The Texas Corp. | 15,500,000 | 6,750,000 | 10,500,000 | 7,692,712 | 16,656,065 | + 116.5 | 42,500,000 | 20,500,000 | 17,500,000 | 33,692,712 | 40,063,433 | + 18.9 |
| Tide Water Associated Oil Co. | 4,474,733 | 2,424,200 | 2,048,908 | 1,152,760 | [3]3,543,348 | + 207.4 | 12,171,435 | 8,416,905 | 4,380,318 | 7,057,625 | 9,790,595 | + 38.7 |
| Union Oil Co. of California | 3,650,000 | 1,450,000 | 1,898,569 | 1,198,232 | 1,911,682 | + 59.5 | 8,850,000 | 6,400,000 | 4,549,713 | 3,212,612 | 5,087,577 | + 58.4 |
| H. F. Wilcox Oil & Gas Co. | 13,558 | 95,878 | 109,409 | 31,839 | [3]95,577 | + 200.2 | 75,241 | 229,279 | 290,468 | 72,771 | 183,132 | + 151.7 |
| Total for 22 Companies | 69,613,334 | 36,785,628 | 32,804,212 | 29,716,042 | 64,646,101 | + 117.5 | 178,524,387 | 105,567,867 | 68,272,954 | 109,218,981 | 149,418,352 | + 36.8 |
| Percent of 1937 | 100.0 | 52.8 | 47.1 | 42.7 | 92.8 | ..... | 100.0 | 59.1 | 38.2 | 61.2 | 83.7 | ..... |

* Loss. [1] Before Federal Income Taxes. [2] Based on comparison of Company's second quarter and third quarter reports. [3] Includes non-recurring profits of $250,000 from sale of property. [4] Compiled from Company's quarterly reports.

## *CGNA Program Deals With Aviation Gasoline*

The contribution of the natural gasoline industry to the increase in output of 100-octane aviation gasoline was the theme of the fall meeting of the California Natural Gasoline Association, Ambassador Hotel, Los Angeles, October 31. The meeting set a record in attendance, as it was scheduled the week previous to the annual meeting of the American Petroleum Institute in San Francisco. More than 450 attended.

W. C. Dayfuss, president, said of the aviation gasoline need:

"The government has indicated that the supply of gasoline must be doubled, possibly trebled, in the near future. Acting promptly on this matter the refining committee of District 5 has made a survey of supplies of isobutane, normal butane and isopentane available in natural gases with a view of effecting their maximum extraction and delivery to aviation gasoline refining centers. While we are extracting a comparatively high percentage of isobutane at present, its extraction must be further increased in many instances. This will call for additional extraction and rectification facilities."

The needs of aviation gasoline and their relation to the natural gasoline industry were outlined by Paul M. Raidorodsky, assistant director of production in charge of the natural gas industry, Office of the Petroleum Coordinator, as follows:

"A development of recent years is the production of 100-octane aviation fuel by alkylation. In a typical alkylation process concentrated sulphuric acid is employed as a catalyst to alkylate isobutane with butylenes. Butylene is a product of the cracking still but while some isobutane is produced from the same source and from crude oil processed in the plant, the main source of isobutane is the natural gasoline plant. In the recent past gasoline plants as a whole extracted isobutane in a butane-isobutane mixture in excess of what was required to produce natural gasoline, only when they had a market for the product. The price was exceedingly low but the advent of alkylation and related processes, stimulated the demand for isobutane and increased its production. In a number of plants where analysis showed commercial quantities of this hydrocarbon facilities were installed for its extraction and separation. Prices for the product have averaged two to three times the price for normal butane.

"The isomerization and dehydrogenation of butane into isobutane, however, will tend to decrease this ratio in proportion to the percentage of conversion less the cost of processing. It will also increase the use of butane for the benefit of national defense while making more room for the use of propane as a fair substitute for the numerous uses of butane at present."

Technical aspects of the use of natural gasoline as part of aviation fuel were brought out in the paper on "Polyform and Gas Reversion Processes and the Natural Gas Industry," by E. R. Smoley, The Lummus Company, New York. He dealt with this refining process in all phases and of natural gasoline and aviation fuel said:

"The use of natural gasoline in the direct manufacture of 100-octane aviation gasoline simultaneously with high-octane motor gasoline is an application for the Polyform and Gas Reversion processes, which interest all natural gasoline producers. The hypothetical operation shown in the following example indicates a high potential production of 100-octane aviation gasoline from field casinghead. For example, consider a producer who has available 5000 barrels daily of 26-pound casinghead containing approximately 3000 barrels of isopentane-free natural gasoline, 350 barrels daily of isopentane, 1100 barrels daily of normal butane and 550 barrels daily of isobutane. This stock would be deisopentanized and debutanized and the gasoline separated by distillation into aviation base stock and a heavy naphtha. The heavy naphtha, 1500 barrels daily, would be polyformed with 1100 barrels daily of normal butane for the production of 1300 barrels daily of 76-octane motor gasoline and at the same time a by-product butane-butylene stream would be withdrawn and charted to an alkylation plant along with the 550 barrels daily of isobutane with a production of approximately 1000 barrels daily of 93-94-octane aviation alkylate. The normal butane from the alkylation operation would all be recycled to the polyform plant. The alkylate would be blended with the 350 barrels daily if isopentane and 500 barrels daily of the aviation base stock produced from the original natural gasoline, resulting in a net production of 1850 barrels daily of leaded 100-octane gasoline. Thus a charge of 5000 barrels of 26-pound casinghead of the characteristics noted would produce 1850 barrels of 100-octane aviation gasoline plus 2300 barrels of 73 ASTM-octane motor gasoline. This example indicates a high volumetric yield of 100-octane aviation and high-octane motor gasoline from the original natural gasoline charge."

George P. Bunn, Phillips Petroleum Company, Bartlesville, and a former president of the Natural Gasoline Association of America, presented a paper, "Human Engineering in the Petroleum Industry." Wallace Williams of the same company was one of its authors. It dealt with the relationships between a corporation and the employe with emphasis on the accomplishments in the petroleum industry.

P. C. Dixon of Foran, Boatright & Dixon, had a paper on "Natural Gasoline Practice as Applied to Cycling." Field practices as well as plant operation were outlined.

"Partial Volume and Its Significance" was the subject of Dr. B. H. Sage and Dr. William N. Lacey, California Institute of Technology.

# The Look Box

### CONVENTIONS

| | |
|---|---|
| JAN. 15–16 | Society of Automotive Engineers, Book-Cadillac Hotel, Detroit. |
| MAR. 22–23 | American Society of Mechanical Engineers, Houston. |
| APR. 15–17 | American Institute of Mining and Metallurgical Engineers, Cincinnati. |
| 16–17 | National Petroleum Association, Hotel Cleveland, Cleveland. |
| 21–23 | Southwestern Gas Measurement Short Course, University of Oklahoma, Norman. |
| 23–24 | Petroleum Industry Electrical Association, Shreveport. |
| MAY 13–15 | Natural Gasoline Association of America, Mayo Hotel, Tulsa. |
| 16–23 | International Petroleum Exposition, Tulsa. |
| JUNE 8–11 | American Society of Mechanical Engineers, Cleveland, Ohio. |

## *Questions and Answers For WPRA Program*

The November meeting of the technical group of the Western Petroleum Refiners Association, Shreveport, November 14, was restricted to questions and answers. A. W. Trusty, chief chemist of Arkansas Fuel Oil Company, had charge of the program. More than 50 questions were submitted prior to the meeting in the Washington-Youree Hotel.

## *Meter School to Meet April 21-23*

Dates for the 1942 Southwestern Gas Measurement Short Course have been set for April 21, 22 and 23.

The meeting will be held at the University of Oklahoma, Norman, where previous sessions have been held.

The dates were fixed at a second meeting of the general committee in Dallas, after it was learned that dates previously selected would conflict with the meeting of the Mid-West Gas Association in Sioux City, Iowa.

## *Chemical Industry Award To Elmer K. Bolton*

The Chemical Industry Medal for 1941 was presented November 8 to Dr. Elmer K. Bolton, chemical director of E. I. du Pont de Nemours Company, at a joint meeting of the American Section of the Society of the Chemical Industry, the New York Section of the American Chemical Society and the New York Section of the American Institute of Chemical Engineers.

The presentation was made by Dr. Wallace P. Cahoe at the Chemists' Club, New York.

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Dr. C. D. Lowry, Jr., Universal Oil Products Company, spoke before the Engineers Club of Ponca City, Oklahoma, November 5, on the subject, "Refining Gasoline—1942 Model." The address covered all recent developments in the field.

He spoke October 25 before the Wichita, Kansas, chapter of the American Chemical Society on "The Newer Chemistry of the Petroleum Gases," in which he discussed the bearing of this development on the production of special products for national defense.

# National Defense Theme Predominates at A. P. I. Annual Meeting

Federal control along with international and military influences on the petroleum industry were outstanding topics of the twenty-second annual meeting of the American Petroleum Institute, November 3 to 7, in San Francisco.

Speakers at the first general session were: William R. Boyd, Jr., Institute president, who made a plea to the effect that the industry be left free to work in cooperation with the national defense program and that it perform its duties in a manner to justify removal of restrictions at the end of the emergency; William P. Cole, Jr., member of Congress from Maryland, who warned that any failure to meet these demands might be seized upon without justification as a basis for permanent control; Harold L. Ickes, petroleum coordinator, who pointed out that wasteful practices by the industry were the only justification for federal control and that present coordination was purely a temporary emergency measure.

Speakers at the second general session were: Ralph K. Davies, deputy petroleum coordinator for national defense, who warned that both the public and the industry should anticipate possible shortage; Walter B. Pyron, special assistant to the under secretary of war, who asked that the industry accept the challenge of the national defense program; Commander T. D. Galbraith of the Royal Navy and a member of the British Parliament, who recounted the war effort in England and predicted victory for his country and its allies; and Alfred P. Haake, National Association of Furniture Manufacturers, who called upon business as a whole to strive for better production methods.

Particular significance was attached to the following statement by Coordinator Harold L. Ickes:

"I view the office of the petroleum coordinator as an agency created to do a necessary work during the emergency—an agency that will be discontinued when the emergency ends."

Speaking of control power of the coordinator, Ickes said:

"All of you also ought to know that my duties under the order issued by the president are merely those of a coordinator. I have neither the power nor the will to impose federal control upon the oil industry."

Much of the speech of the petroleum coordinator was devoted to a review of the activities of his office, a discussion of the tank car situation and the controversy that attended it, also to a discussion of the return of tankers by Britain. His reference to federal control of the petroleum industry started on the premise that he had no desire to bring that about, had no authority for it and that he knew of no disposition on the part of the government to accomplish it. He placed himself on record as believing profoundly in conservation, which he described as "prudent use, while preserving for the welfare and happiness of our children and theirs, all that we do not actually need for ourselves."

### Interested in Conservation

"What I am leading up to is that if the federal government ever imposes any measure of control over the oil industry, it will be in the interest of conservation. Wasteful practices, sooner or later, bring some type of federal control. And wasteful practices in the oil industry will also bring some measure of control, probably not during my tenure of public office, but yet surely and in-

# Weymouth Receives Munroe Award

Thomas R. Weymouth was awarded the Charles A. Munroe Award at the American Gas Association's annual meeting in Atlantic City, October 21, for having made the most outstanding recent contribution toward the advancement of the gas industry.

Consisting of a substantial financial acknowledgement and engrossed certificate, the award was made to Weymouth for his leadership of organized research activities and for his individual accomplishments of a fundamental and permanent nature. Among achievements over a period of years which led to his selection for this honor are:

He experimented extensively in the operation of gas compressors and engines and developed formulas for computing the gas delivery capacity and power requirements of compressors. He invented a special type of gas cooler for increased efficiency and collection of condensates.

He collaborated in the first practical determination of the deviation of natural gas from Boyle's law and conducted independent research on this subject, developing an approximate simplified method of securing the result. He also developed new instruments for determining the specific gravity of natural gas and collaborated with the National Bureau of Standards in a study of the efficiency and accuracy of the devices then available.

He conducted independent research on the extraction of gasoline from natural gas and collaborated in the development of the charcoal process. He collaborated in the development of the Oliphant pitot tube and developed the so-called Weymouth Formula for the flow of gas in pipe lines.

Weymouth invented one type of orifice meter and established the coefficients which formed the basis of measurement by the Foxboro meter for gas and other fluids until the revision made by Gas Measurement Committee of the American Gas Association in 1935. He was chairman of the latter committee from its origin to date. He also has done research work on the underground storage of natural gas; in fact worked on some of the earliest experiments.

Born on March 16, 1876, at Lock Haven, Pa., Weymouth was graduated from Massachusetts Institute of Technology in 1897. In 1943 he became assistant engineer for National Transit Company, Oil City, Pennsylvania. His duties involved engineering work with various gas companies and in 1911 he joined United Natural Gas Company, Oil City, as assistant engineer, was soon made chief engineer and later was also chief engineer for Pennsylvania Gas Company, Warren, Pennsylvania.

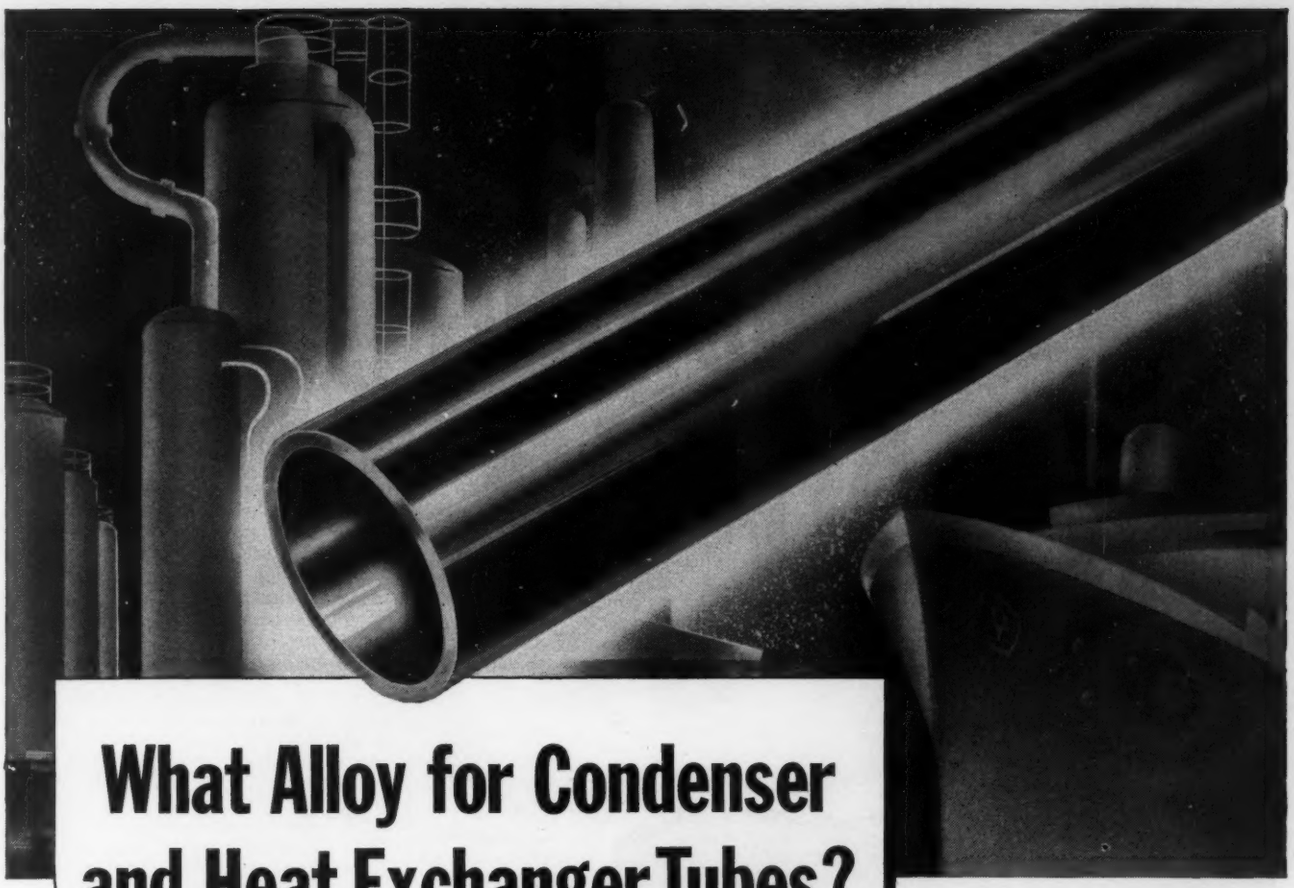
THOMAS R. WEYMOUTH

In 1923 he became president of the Iroquois Gas Corporation, Iroquois Building Corporation, and Snyder Natural Gas Company, Buffalo, New York. Five years later, in 1928, he went to Tulsa, as president of Oklahoma Natural Gas Corporation and American Natural Gas Company, where he remained until 1930 when he joined Columbia Gas & Electric Corporation as vice president in charge of operations, from which position he retired on April 1, 1941.

Weymouth was a member of the Natural Gas Association of America since 1911, and, since its merger, has been a member of the American Gas Association, serving as chairman of the Natural Gas Section in 1938-1939. As a member of the main technical and research committee and chairman of the gas measurement group, he has provided leadership in the association's research program.

In 1920, Weymouth was consulting engineer for Public Utilities Commission of Alberta, Canada, in one of its cases and was a member of the arbitration commission for the adjustment of the rates of Canadian Western Natural Gas Light, Heat & Power Company.

The Charles A. Munroe Award Committee consisted of C. L. Campbell, chairman, F. H. Lerch, Jr., and D. A. Hulcy.

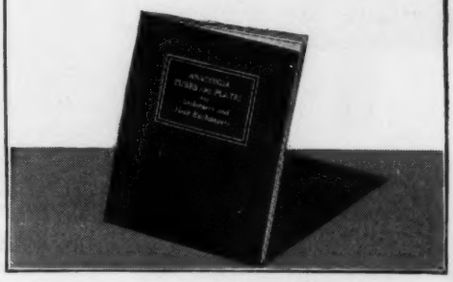


# What Alloy for Condenser and Heat Exchanger Tubes?

To obtain maximum service life for condenser tubes there are many operating factors to be considered—character of the cooling water, turbulent flow, and entrained air, to name but a few. Naturally your tube alloy should be selected in accordance with the combination of these factors existent in your plant.

Through their unparalleled experience in the field, Anaconda engineers have accumulated a vast fund of knowledge with which to meet these problems. Their service is available upon request. They can cooperate in ana'yzing your requirements and place before you performance records of copper alloys under similar operating conditions. No charge is made for such consultation. 41118

**The American Brass Company manufactures a wide range of tube alloys for condenser and heat exchanger installations. They are fully described in our latest Condenser Tube Publication B-2, which will be sent upon request.**



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# HERE IS THE MULTI-METAL ANNOUNCEMENT THAT IS MAKING BIG NEWS

**There is vital information in this booklet for your production staff, concerning specialized fabrication equipment now available for outside use for the first time.**

**This booklet may well contain the answer to an urgent specialized fabrication problem in your own plant. A copy is yours just for the asking.**

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evitably. The way, and the only way, in which to make unnecessary such control as will prevent waste and intemperate exploitation will be for you to exercise that measure of self control which will persuade the government that you are managing your own affairs so competently, so wisely and so patriotically as to make unnecessary any interference by the people.

"May I say, out of my friendly interest in the oil industry, and, as a man who has come to know you and to appreciate you, better than I once did, that such practices as obtain in my own state of Illinois and in this state of California, are better calculated to bring about at least some measure of federal control of the oil business than a thousand 'would-be czars.' You have had the power to stop those practices; you have such power today. But you have not exercised it."

The petroleum coordinator outlined the situation and prospects as to 100-octane aviation gasoline as follows:

"All of us know that a grave inadequacy has been rapidly developing as to 100-octane aviation gasoline. In fact, some of you were in Washington on August 12, when I asked that immediate steps be taken to double our 100-octane manufacturing capacity. Later, when it became evident that even this would not provide for already foreseeable demands, I set in motion processes to determine how we could not only double, but treble, our output.

"A nation-wide survey, as of mid-October, demonstrated that our manufacturing capacity of 100-octane gasoline amounted to a total of 43,278 barrels a day. Plants now nearing completion will add 2,557 barrels daily by January 1, 1942. Additional arrangements have been made which will mean another 11,994 barrels a day by January 1, 1943. Thus, we discover that thirteen months from now our over-all production of 100-octane gasoline will be an inadequate 57,829 barrels daily.

"The country will not be satisfied with such a meager effort. A potential of 100,000 barrels daily by January 1, 1943, will not come anywhere near supplying our own needs, in addition to those of Britain, Russia, and China. Fortunately, we can increase our 100-octane capacity to 100,000 barrels daily by January 1, 1943, if the refiners are willing to do what our survey indicates ought to be possible. Capacity can be boosted during the next year by about 41,700 barrels. This would make a national output of approximately 100,000 barrels daily by 1943. There is also the possibiilty of adding another 3000 barrels by the improvement of base stocks.

"Even if we achieve this result we will still be 20,000 barrels daily short of what the forecasts indicate that we shall need by 1943.

"Your government stands ready to assist in the financing of new refining facilities and equipment. Secretary Jones has said that he will be willing to enter into contracts on behalf of the government for your future production of 100-octane gasoline covering a period of from two to three years. The oil industry has risen to many an emergency in the past. It will not refuse the hurdle when its country is mustering all of its resources to defeat a man who is proving himself to be a brigand on land and a pirate on the high seas.

"Unfortunately, we are not even sure that we have sufficient capacity for pro-

# ADDITIONAL SAFETY INSURANCE

## FOR HIGH TEMPERATURE • HIGH PRESSURE PIPING

# MIDWEST GLOBACK JOINTS

Called "Globack" because the back face of the lap is a segment of a globe or sphere, this high pressure pipe joint is a big improvement upon regular lapped (Van Stone) joints. Developed by Midwest, "Globack" Joints have these important advantages: (1) in critical area of lap, the metal thickness is much greater than pipe wall thickness, consequently the lap is stronger in shear; (2) distribution of bolting pressure is uniform, and fair seating of flanges is assured; (3) bending moment to which the lap is subjected is less because the maximum stress is removed from lap periphery and the resultant bolting force is shifted toward the pipe wall.

The Midwest "Globack" principle is also applied to other flanged joint facings: tongue-groove, male-female, etc. Let us tell you about some of the recent outstanding high pressure, high temperature central station piping installations that have Midwest "Globack" Joints.

MIDWEST "GLOBACK" (VAN STONE) LAP

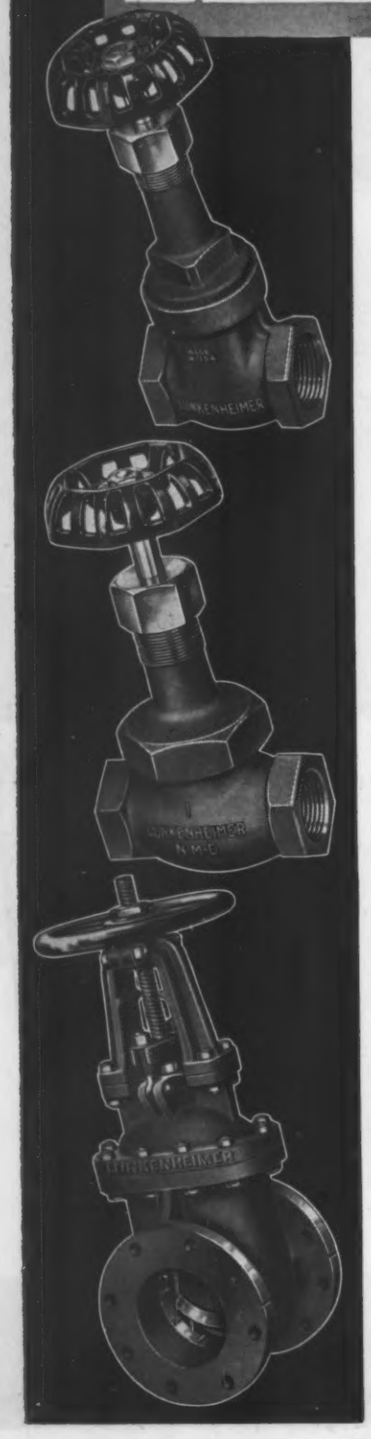
Dotted line indicates full pipe wall thickness (Van Stone) lap, and shows that Midwest "Globack" Joint provides maximum strength in critical lap section—where strength is most needed.

**MIDWEST PIPING & SUPPLY CO., Inc., Main Office: 1450 S. Second St., St. Louis, Mo.**

Plants: St. Louis, Passaic (N.J.) and Los Angeles • Sales Offices: Chicago—946 Marquette Building • Houston—229 Shell Building
Los Angeles—520 Anderson Street • New York—(Eastern Division) 30 Church Street • San Francisco—426 Call Building • Tulsa—833 Mayo Building

*You buy fewer valves when you buy*

LUNKENHEIMER



**Why? Because Lunkenheimer construction features minimize wear and insure longer service life with less maintenance.**

**The use of non-corrodible alloys at vital points—design and construction that eliminate excessive wear of working parts—thorough, scientific tests of every valve before shipment—are features of Lunkenheimer Valves that make for longer life, fewer repairs, continuity of service, and lower costs.**

**Actually you need fewer valves when you use Lunkenheimer because they give you less trouble and stay in service longer. This is extremely important now when virtually all materials have become increasingly necessary to defense activities. You can help conserve these needed materials—insure valve satisfaction—buy fewer valves . . . by specifying Lunkenheimer.**

**Your Lunkenheimer distributor is cooperating in every way to give you the kind of service you so vitally need for the National Defense program. His facilities will save you time and trouble.**

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"QUALITY"
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EXPORT DEPT. 318-322 HUDSON ST., NEW YORK


ducing all of the ordinary gasoline that we will need. Our refiners of motor fuel are now pretty close to 100 percent capacity and the demand continues to rise.

"Together, the federal government and the oil industry have already done much. But while we may stand proudly upon our record, we must not go to sleep upon it. The most important tasks lie ahead. If the possession of oil will determine the conflict that rages in Europe, we cannot fail to supply whatever petroleum may be necessary to achieve our objective. We have the oil and the tankers, but it is up to you men, who, by your initiative and daring, have made this the great industry that it is, to see to it that the petroleum products are produced in such quantities and of such types as may be necessary to keep a full line of tankers carrying them to those who are fighting America's battle—100-octane gasoline for their airplanes, regular gasoline for their trucks and tanks and fuel oil for their ships."

### Oil Legislation

The role of the legislative branch of the federal government in its relation to the petroleum industry was summed up by Representative William P. Cole, Jr., as follows:

"I am in agreement with Governor Jones of Louisiana and others who have voiced the conviction that the people of the United States must be informed regularly on what is being done in the development, transportation and conservation of petroleum for the public welfare by the industry, the state regulatory authorities, the Oil Compact Commission and the state and federal governments. This valuable information will develop the people's appreciation of the great strides that the oil industry has made and impress on them the tremendous part that petroleum plays in their lives and in the success of the defense program.

"Under the guidance of the American Petroleum Institute and other organizations, the public is gathering some knowledge of the technological progress that is being made by the industry and how that progress affects the public's everyday life.

"It is necessary that the public obtain a practical knowledge of many phases of the oil industry if it is to be sympathetic with the industry in emergencies such as the national defense program and its extraordinary demand on the oil companies. This understanding of problems that may arise, such as the recent one of transportation, can be attended only by the wise dissemination of information.

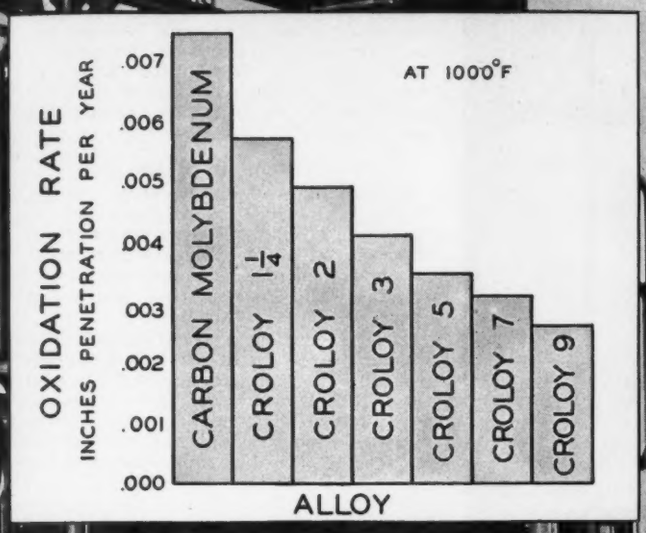
### Must Be Unity

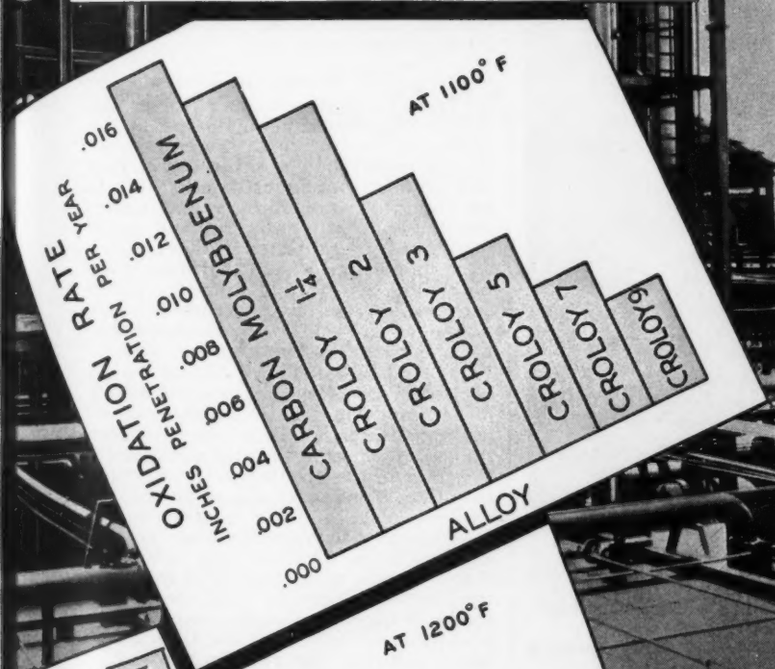
"Unanimity of purpose is the backbone of the national defense program and there must be no discord at this time. There must be a powerful unified movement of citizens, producers and state and federal officials in order to make conservation a part of the defense program. There must be an uninterrupted flow of petroleum from producers to consumers, whether they be civilian or governmental. There should be no undue restrictions placed on the oil industry by state and federal authorities if our gigantic task is to be accomplished and the American way of life to be continued at all times.

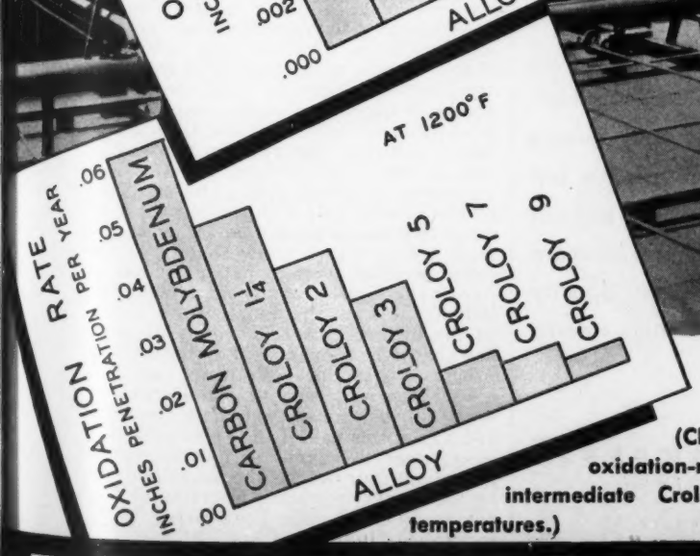
"You who believe in free enterprise regulated in the public interest or in what may be called 'humanized business' have to meet a challenge of making that system constantly even better for

# Conservation for Defense!

## AND PRODUCTION




(Charts giving oxidation-rate data on intermediate Croloys for 3 temperatures.)

**B&W Intermediate Croloy Tubes are satisfactorily replacing higher-alloy grades in many important refineries. But be sure you select the *right* Croloy for your needs — not just the easiest-to-get Croloy.**

**The B&W Intermediate Croloys are low-chrome-molybdenum steels offering good corrosion resistance and creep strength. They are made (on priority of course) in tube and pipe sizes covering all refinery requirements.**

**Thus you can reduce metal loss from oxidation to a minimum while conserving strategic metal for defense without endangering continuity of operation.**

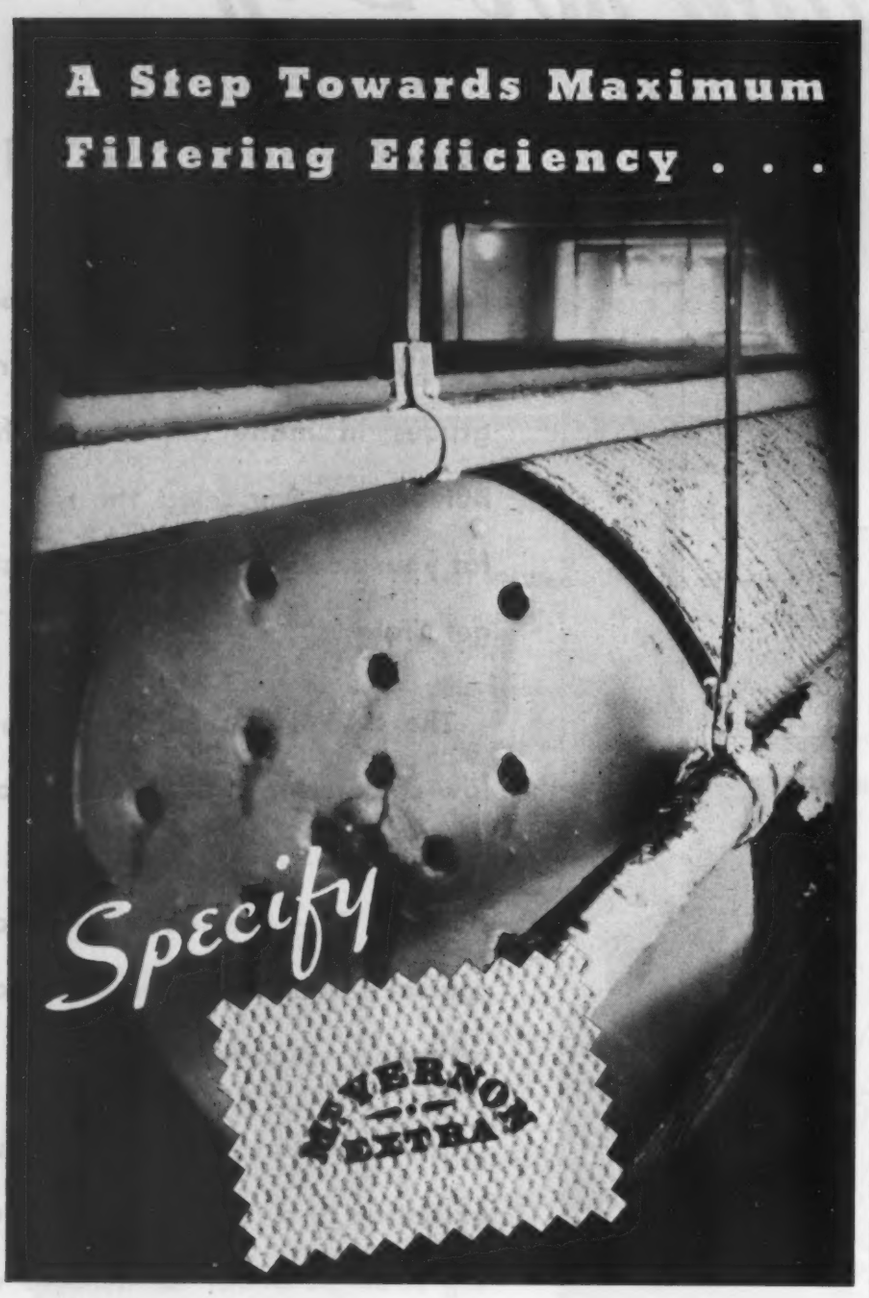
**Complete technical data will be sent on request. The B&W engineering staff can show you promptly where and how to employ these Croloys most effectively.**

TA 118

# BABCOCK & WILCOX TUBES

HOT FINISHED COLD DRAWN ALLOY STEELS CARBON STEELS

THE BABCOCK & WILCOX TUBE COMPANY BEAVER FALLS, PA.




MT. VERNON Extra filter fabrics will help your plant to obtain greater efficiency in filtering operations. Their high degree of uniformity insures maximum filtering surfaces and permits maximum pressures to be employed. They are made from a top quality of cotton and show great resistance to wear. They are the product not only of the most modern textile machines but of more than half a century's industrial fabric making experience. Specify MT. VERNON Extra filter fabrics. They are a direct step toward maximum filtering efficiency.

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the commonwealth. Any failure to meet the peak loads of these crowded days will be seized upon by the enemies of free enterprise as an excuse for the taking over and nationalizing of industry. The excuse may not be valid but the loads imposed on industry by government may be arbitrary and unpredictable.

"Reassured as I have been at this meeting, I shall return to Washington deeper in my conviction that the challenge of certain tyrannical powers has only served to strengthen the purpose and resolve of the United States of America that free government shall not perish but live on in its renewed strength and security."

### Tribute to Byles

In opening the first general session, William R. Boyd, Jr., paid a tribute to Axtell J. Byles, who was president of the Institute until his death September 28. He cited the accomplishments in standardization as one bit of evidence of the work of the Institute.

He quoted from a recent statement of Coordinator Ickes before a Senate committee to show the attitude of the official toward preservation of free enterprise and pledged that the petroleum industry would support and cooperate in the effort. The record of the industry in the first world war was reviewed and cited as evidence of the ability of the industry to carry its share in any emergency. He put the attitude of the industry in the current emergency as:

### Free Enterprise Plea

"I am confident that whatever demands may be made upon the oil industry or, in fact, upon the entire productive establishment of the nation, they will be met. Our industry asks only to be permitted cooperatively and understandingly to work out its own methods; that it be subjected to no suspicion as to its patriotism; and that it be given no reason to fear that honest, friendly cooperation with our government today may open the way to totalitarian domination or control tomorrow.

"The oil industry's whole history has been a record of surmounting obstacles, of accomplishing the impossible and of dealing with crises. In oil we have been trained to expect always the unexpected. Whether in the production of crude oil, the diversification of its products, the improvement of their quality, or in meeting requirements for ever-increasing quantities of them, our industry's record stands without parallel in industrial history. Year by year, petroleum products have gone to the consumer at progressively reduced costs. In quarters where criticism was readiest and sharpest, it has won acclaim as a model employer of labor. While the statistics of commodity prices show that those in the petroleum group are the cheapest, the statistics of wages show that in petroleum refining average pay per hour is one of the highest in any manufacturing industry. To put these statistics in terms of the buying power of wages we may say that over a quarter of a century the price of gasoline — exclusive of the ubiquitous, excessive gasoline taxes — dropped just about one half, but the average wages paid by a typical oil company, over the same period, increased just about four times. The buying power of the worker's wages, in terms of the commodity he was producing, had multiplied eight times.

"The president has designated Secre-

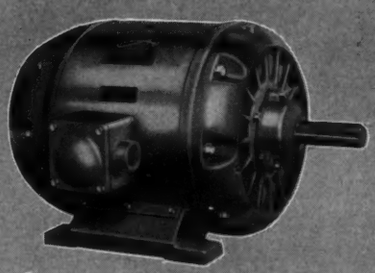
Compare Louis Allis Explosion-Proof motors point by point with any others on the market—

*And we are sure you will agree that they are the finest explosion-proof motors ever built —bar none!*

One of the twenty carefully engineered features of these explosion-proof motors is shown above—

*This is the inside of the endbell — note the extra long closely machined rabbet fits—and the strongly reinforced cast iron construction.*

These endbells are scientifically reinforced inside and out to withstand any likely internal explosion, with a safety factor of FIVE!



*The very first fan-cooled explosion-proof motor was originated, developed, patented and pioneered by The Louis Allis Co.*

As the originator—and pioneer—The Louis Allis Co. has more actual years of manufacturing and operating experience with this type motor than any other manufacturer—

*The present Louis Allis Explosion-Proof motor now makes available a new high in electric motor efficiency, dependability, convenience, long life —and SAFETY.*

We earnestly solicit your inquiry — write for copy new twenty page descriptive bulletin No. 508E.

**THE LOUIS ALLIS CO., MILWAUKEE, WIS.**

tary Ickes as Petroleum Coordinator for National Defense, and from the ranks of our industry, our friend Ralph Davies, has been named deputy coordinator. Our industry should fit itself into the proper national defense scheme of organization in order to conduct effectively all activities for national defense purposes. We shall quickly adjust ourselves to the unified demand of war, but the building of our most effective oil organization for defense purposes can not be done overnight; it must come through trial and error processes.

"In conclusion, let me repeat, that the better we cooperate and serve now, the prouder we shall be of the job done; the more we shall be entitled to be released from governmental controls, hampering restrictions, and every interference with the right of free enterprise to render its full service to the public weal. Thus shall we make our supreme contribution toward preserving and perpetuating our great fundamental rights of representative political democracy, civil and religious liberties and economic freedom."

### Davies' Statements

Ralph K. Davies, the deputy coordinator, pointed out that only the marketing division of the industry has ample facilities for the immediate future. He made it plain that no shortages now exist in either production or refining but as to production he said that recently he had been asked this question:

"Can the oil industry produce 5,000,000 barrels per day without injury to its properties and, if so, over what period of time can this rate be maintained?"

In regard to refining he summed up recent advances in daily throughput and said:

"All of this means that in refining, as in production, many of the old familiar beacons by which we have been guided so long are facing into the fog of world disorder. We are confronted with new and vastly different conditions, with new problems to be taken carefully into account in setting our course at this critical time."

After recounting the recent crisis in tanker transportation to the Atlantic Seaboard, Davies left this warning as to the future in transportation:

"Ill fortune could create a deficiency of 50 or 100 tankers overnight, and we should be prepared for the adversity."

The assistant petroleum coordinator summed up the situation as to refining as follows:

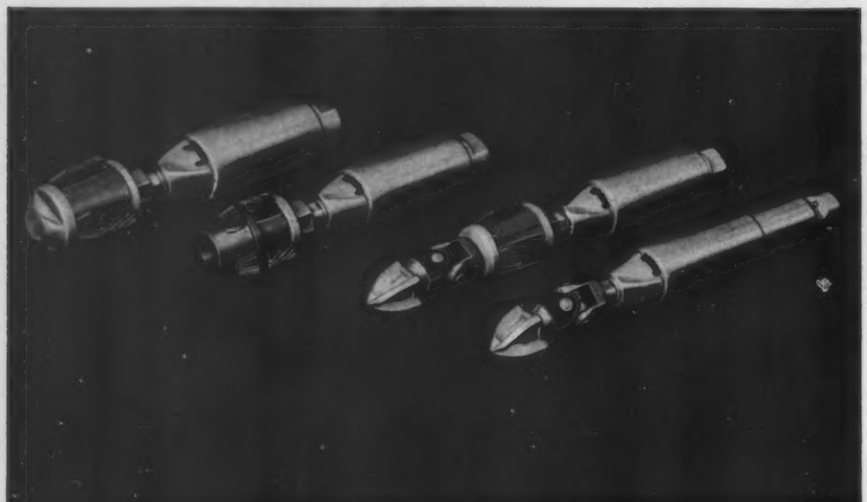
"It seems to me our exact position can be determined rather readily. As stated to you by the Coordinator, in most sections of the country our efficient refining facilities are operating now virtually at capacity. Such margin as still exists is for the most part either a statistical abstraction, or of such character as to be unsuited for the kind of products we need most, even if we can obtain the materials necessary to place it in operation. With respect to our country's production of aviation gasoline, we find ourselves faced with the necessity of at least doubling, and much more probably trebling, our capacity. Likewise, we apparently lack, though not to the same degree, sufficient plant for refining the increased volumes of high-viscosity lubricating oils which the defense program will require.

"In addition to the difficulties in maintaining product balances which have been disrupted by transportation shortages and by the radically altered character of the products demanded for defense, we find now the need for curtailing the use of tetraethyl lead. The deficiency here results from an increased need for lead in other defense industries. The petroleum industry could not have anticipated any such development, but the industry is faced, nevertheless, with the task of producing the enormous quantities of high-octane material needed by the Army and Navy and Lend-Lease accounts, without even as much of this vital blending agent as we have had heretofore.

"Crude runs to stills have now reached 4,060,000 barrels per day—an increase of 495,000 barrels per day over this time last year, and the highest record of all time for this or any other country. Clearly, additional refining capacity is required, but in what amount, and how readily the necessary materials can be obtained by the industry in order to accomplish this expansion, are disturbing questions facing us at the present time. Many other industries as essential as our own in the defense effort are calling for the same critical materials which are needed in petroleum refining, and these competing demands must be recognized.

"In the light of these facts it becomes of the utmost importance that existing facilities be operated with the greatest skill and at maximum efficiency. Further, that such unused capacity as may be available throughout the country be placed in operating condition and utilized even with higher costs, as consumptive demand forces this extremity.

"All of this means that in refining as in production, many of the old familiar

FOR *BETTER* TUBE CLEANING
SPECIFY A *WILSON* CLEANER

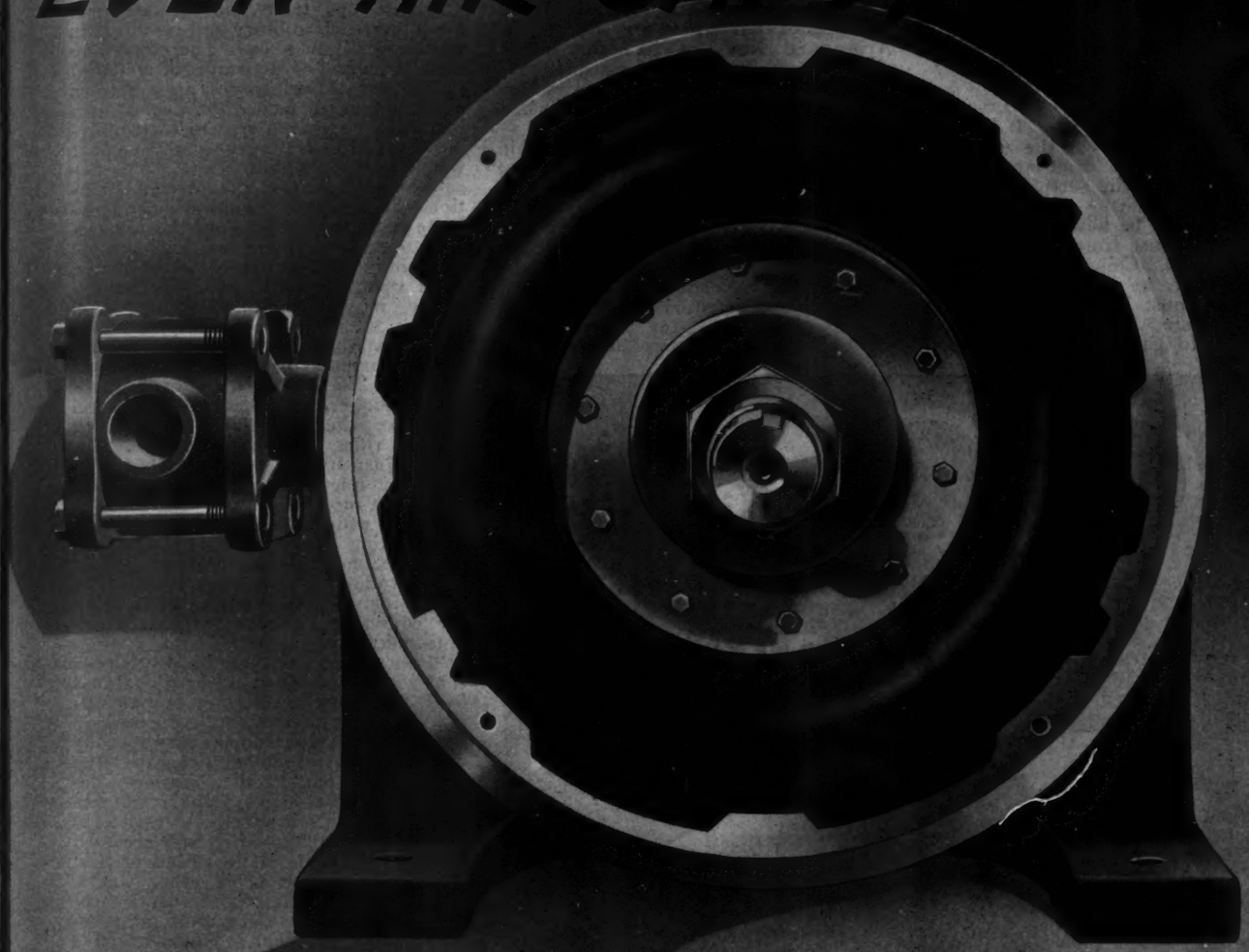
Our national defense effort calls for more and more petroleum products. Because the reduction of down-time to the minimum is essential to the maintenance of maximum production it is essential that the *most efficient* tube cleaning equipment should be used for all refinery tube and pipe cleaning.

In scores of large and small refineries throughout the country Wilson E. P. (Extra Power) Tube Cleaners are doing a *faster, better, more economical* job of tube cleaning. These cleaners and the proper Wilson accessory remove exceptionally hard and heavy coke or thick gummy deposits with equal facility and thus *reduce* down-time and *increase* production. There is a Wilson Tube Cleaner and accessory to meet every refinery tube cleaning need.

Write for the name of our representative nearest to you or send for a copy of our thirty-six page catalog fully describing and illustrating the complete line of Wilson tube cleaning equipment.

**THOMAS C. WILSON, Inc.**
PIPE AND TUBE CLEANERS EXCLUSIVELY
47-28 37th Street Long Island City, N. Y.

# EVEN AIR GAPS



Accurately ground stator bore of Louis Allis induction type motors helps to insure even air gaps and precision electrical balance.

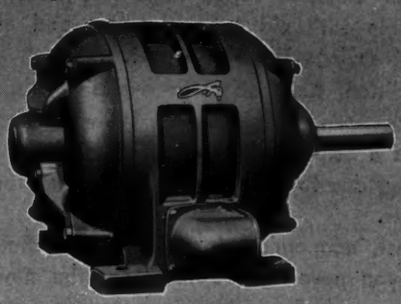
*Precision fit, selected ball bearings, help to insure even air gaps.*

And these—supported by close tolerance machining of stator housing and bearing brackets—and rigid multiple inspection—*insures even air gaps* in Louis Allis induction type electric motors.

*Dynamically balanced, pressure cast one-piece rotors insure mechanically balanced as well as electrically balanced motors.*

Firmly anchored, triple insulated stator windings—in a scientifically braced, extra heavy one-piece cast iron housing insures extra rigidity—and smooth flowing, dependable power on the very toughest jobs.

*There is a size and type Louis Allis induction electric motor for every industrial requirement.*



Write for a copy of our new illustrated catalog No. 701

*We earnestly solicit your inquiry on your very next electric motor requirement.*

**THE LOUIS ALLIS CO., MILWAUKEE, WIS.**

beacons by which we have been guided so long, are fading into the fog of world disorder. We are confronted with new and vastly different conditions, with new problems to be taken carefully into account in setting our course at this critical time."

### Pyron Speaks

Brigadier General Walter B. Pyron, former vice president of the Gulf Oil Corporation, Houston, dealt largely with the relationship of the petroleum industry to general industry and suggested that every effort be made to exact the full measure of use from all equipment, especially steel. Concerning desirable oil field practice he said:

"Industry must lay aside all selfishness and desire to capitalize on the emergency, to gain a favored position or to demand, for example, critical materials when some less essential material could be used. If, for example, the industry demands nickel, steel or other products of that nature, you deprive the Army and Navy of just that much material which must be used in the manufacture of tanks, guns, etc., which cannot be made of substitute materials. War is destructive and wasteful.

"In peace times an obsolete battleship or merchantman is salvaged and at least a considerable part of it is returned to industry in the form of junk to be reformed into useful products for the country; but a ship sunk in the ocean has no recovery value; neither has the shell that is shattered into thousands of pieces and scattered over the terrain of a battlefield. So a large percentage of our output is not coming back to industry, which means that the call on industry increases with the increased activity of the armed forces.

"Battleships, tanks, anti-aircraft guns and other such military and naval needs are not built in a day. Therefore, any delay because of shortage of material places our armed forces at a serious disadvantage in facing the enemy who has a highly geared system for supplying its armed forces with combat weapons and supplies.

"Therefore, under the present situation you can speed up the general defense program by delaying the replacement of machinery and materials beyond the point of what you consider normally, good operating procedure. As an example, if you move a 136-foot steel derrick to a new location, instead of buying a new one you release enough steel to manufacture one medium tank. By using 250 feet of No. 4 rotary chain a little longer, you release enough steel to make the essential parts of 100 Garand rifles. If you can continue the use of just 1000 feet of ⅞-inch sucker rods you release enough steel to make 24 60-mm mortars, and if your pipe department orders 250 feet of 16-inch pipe he is taking out of service enough steel to make one 155-mm howitzer, and if your production man buys 1000 feet of new 7-inch 20-pound casing he is using the equivalent, in steel, of ten 37-mm anti-tank guns.

"I am giving you these illustrations so that you may understand how vital it is for the industry to conserve its materials and machinery to the fullest extent in order that our government may speedily carry out its armament program. The oil industry will make a distinct contribution to the defense plan if it watches its warehouse stocks closely and keep them to a minimum; if it will see to it that no idle material is stored in field or in refinery yards; in other words, put all surplus material to work producing more oil, moving more oil or refining more oil. That is sound business practice, normally, but in this emergency it is not only good business, but will mean the speed-up of the entire defense program."

### Haake Pays Tribute

The address of Alfred P. Haake was a tribute to free enterprise and a plea to business men for following methods which will assure continuation. He said:

"Today we face a solemn choice. We are faced with the alternative of government domination of all enterprise, leading inevitably to the slow strangulation of individual resourcefulness and thus to a static economy, or the preservation of our free enterprise system through vigorous self-discipline and wise regulation. We must decide which road we are to take."

After recounting the accomplishments of free enterprise as it has contributed to American standards of living he added:

"It is pitiful to hear men pronounce ponderously that we must have government control of our economic life in order to preserve democracy. It is no less pitiful to see men reach into the waste basket of history for systems which already have failed as the panaceas to lift us out of our fear-fastened distrust."

### Galbraith Comments

Commander Galbraith expressed the opinion that one of the causes of the present war was, "the world's and par-


ROTO Tube Cleaners for DOUBLE BARRELLED ACTION

Model 135 motor with swing-frame head and air valve for one-man operation.

When you clean tubes with a new Roto, you get double barrelled action—faster action inside the tubes and faster action between tubes.

The powerful Roto motor, rugged, self-feeding heads and sturdy universal joints clean out the most stubborn coke, carbon, sludge or scale faster than ever before possible with old type cleaners, and at great savings in upkeep cost.

In addition, Roto offers its exclusive labor saving one-man operating air valve which eliminates a helper and the starting and stopping delays due to signalling between operator and helper.

For fast, economical tube cleaning action such as you never got before, try the new Roto in your plant.

*SEE OUR ADV. IN SWEET'S AND WRITE*

**The ROTO Company**

145 SUSSEX AVENUE NEWARK, N. J.

# . . . One answer to INCREASED PRODUCTION DEMANDS

## A DOWTHERM* SYSTEM . . .

Provides accurately controlled high temperature heating and cooling.

Insures production of a superior product by preventing decomposition resulting from overheating.

Simplifies equipment problems since it utilizes low pressure equipment.

Evidence of the superiority of the Dowtherm system is illustrated by the large number of companies that have Dowtherm-rejuvenated their high temperature processes.

# DOWTHERM

OTHER DOW CHEMICALS INDISPENSABLE TO THE REFINING INDUSTRY INCLUDE:
*Caustic Soda—Liquid, Solid and Flake; Organic Solvents; Phenols, and Sodium Sulphide.*

THE DOW CHEMICAL COMPANY, MIDLAND, MICHIGAN

New York, St. Louis, Chicago, Seattle, San Francisco, Los Angeles, Houston

ticularly the democratic nations' wish for peace."

For the present he classed the situation as:

"This is a challenge to American industry such as it has never before been called upon to face, a challenge which to meet successfully will call for all the skill, all the efficiency, and all the energy of her great industries; a challenge to her supremacy as the greatest producing country in the world, a challenge to her pride in past achievements but a challenge in which we in Britain see her triumphant, believing that the output, and the excellency of the output of free men, far exceeds that of men in countries where the state has usurped the place of God and they are but slaves and puppets."

## *Boyd Elected API President*

William R. Boyd, Jr., executive vice president of the American Petroleum Institute since 1929, was elected president for the year at the annual meeting in San Francisco, November 3 to 7. It was a re-election, as the board of directors had chosen him to fill out the term following the death of Axtell J. Byles, September 28.

All other officials were re-elected as follows: George A. Hill, Jr., Houston Oil Company of Texas, Houston, vice president for production; J. Howard Pew, Sun Oil Company, Philadelphia, vice president for refining; Eric V. Weber, Eureka Oil Company, Cincinnati, Ohio, vice president for marketing; O. D. Donnell, The Ohio Oil Company, Findlay, Ohio, treasurer, and Lacey Walker, American Petroleum Institute, New York, secretary and assistant treasurer.

All members of the executive committee were re-elected.

In addition to the 47 members of the board of directors that were elected by members, the board itself elected nine to its at-large group and one to the supply group.

The directors elected by the board to its membership are (*indicates re-election) E. R. Brown,* Magnolia Petroleum Company, Dallas; H. R. Gallagher, Woodside, San Mateo, California; W. F. Humphrey,* Tide Water Associated Oil Company, San Francisco; W. A. Jones,* Cities Service Company, New York; H. T. Klein,* The Texas Company, New York; T. Rieber, Barber Asphalt Company, Barber, New Jersey; W. C. Teagle,* Standard Oil Company (New Jersey), New York; Alex Walker, National Supply Company, Toledo, Ohio; L. S. Wescoat,* The Pure Oil Company, Chicago; and Ralph Zook,* Sloan & Zook, Bradford, Pennsylvania.

Rieber succeeds Paul Ryan, National Refining Company, Cleveland. Gallagher was elected to fill the unexpired term of the late E. W. Marland on the at-large group, and Walker will complete the term of the Late P. C. Jones on the supply group.

### Executive Committee

The directors also elected from their membership the executive committee for 1942 as follows: W. R. Boyd, Jr., American Petroleum Institute, New York; J. A. Brown, Socony-Vacuum Oil Company, Inc., New York; Robert H. Colley, The Atlantic Refining Company, Philadelphia; H. D. Collier, Standard Oil Company of California, San Francisco; Henry M. Dawes, The Pure Oil Company, Chicago; O. D. Donnell, The Ohio Oil Company, Findlay, Ohio; W. S. Farish, Standard Oil Company (New Jersey), New York; Jake L. Hamon, Cox & Hamon, Dallas; George A. Hill, Jr., Houston Oil Company of Texas, Houston; William F. Humphrey, Tide Water Associated Oil Company, San Francisco; and R. C. Hunter, Mid-Continent Oil & Gas Association, Abilene, Texas.

Also W. A. Jones, Cities Service Company, New York; F. A. Leovy, Gulf Oil Corporation, Pittsburgh; B. L. Majowski, Deep Rock Oil Corporation, Chicago; J. Howard Pew, Sun Oil Company, Philadelphia; Frank Phillips, Phillips Petroleum Company, Bartlesville, Oklahoma; Charles F. Roeser, Roeser & Pendleton, Fort Worth; W. S. S. Rodgers, The Texas Company, New York; E. G. Seubert, Standard Oil Company (Indiana), Chicago; H. F. Sinclair, Consolidated Oil Corporation, New York; W. G. Skelly, Skelly Oil Company, Tulsa; Reese H. Taylor, Union Oil Company of California, Los Angeles; R. G. A. van der Woude, Shell Union Oil Corporation, New York, and E. V. Weber, Eureka Oil Company, Cincinnati, Ohio.

### Board of Directors

Forty-seven members of the board of directors were elected by the membership at the general session of the Institute's 22nd annual meeting. The new directors, serving two years, succeed members of the board whose terms expired this year, or were elected to fill

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REFINERY EQUIPMENT

*Recognized throughout the Industry for—*

SOUND ENGINEERING

ACCURATE SPECIFICATIONS

PRECISION WORKMANSHIP

**Tulsa Boiler & Machinery Co.**

WEST TWENTY-FIRST STREET & UNION AVENUE TULSA, OKLAHOMA

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## *CATALOGUED for your convenience*

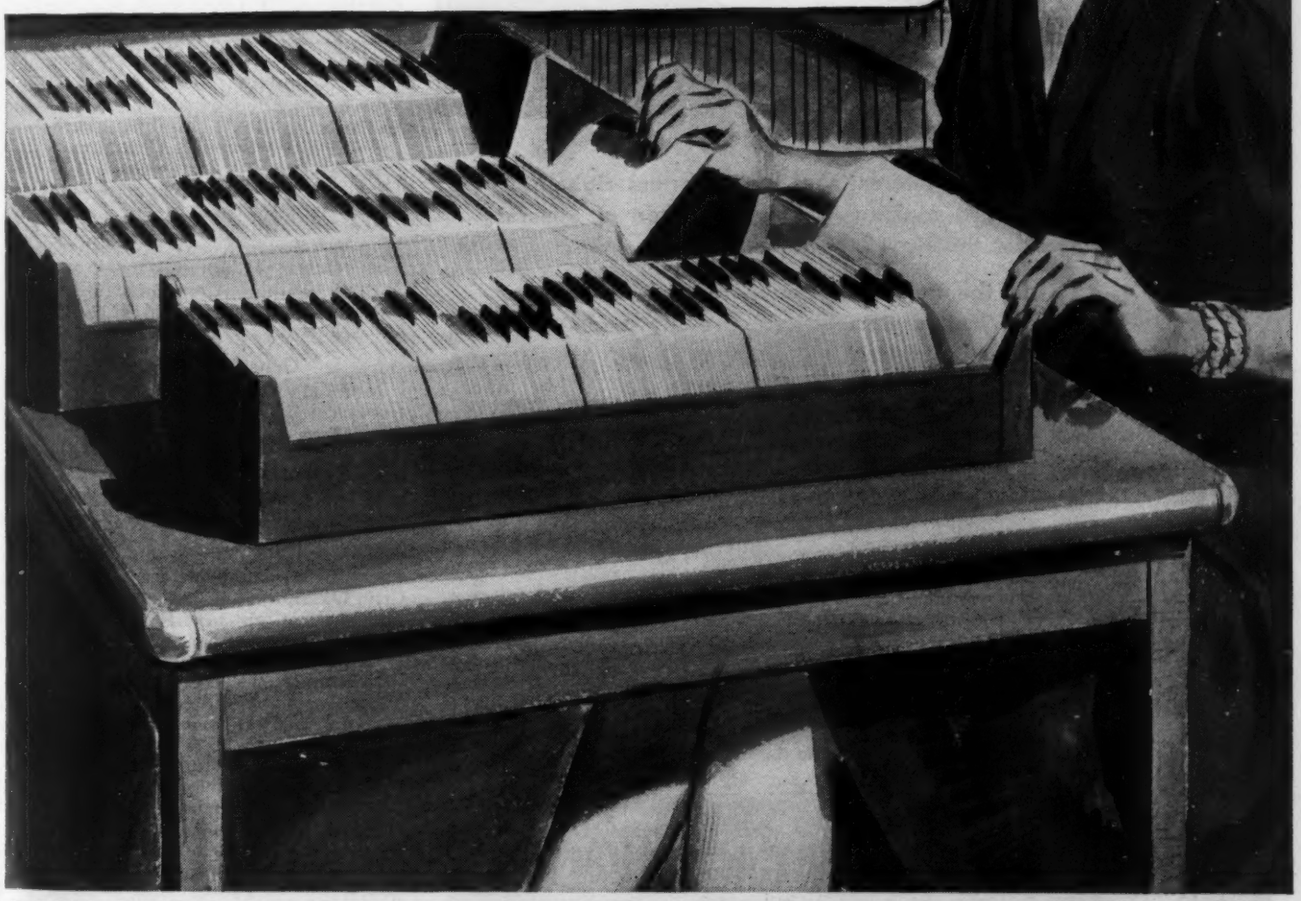
Specific answers to many of your questions about the selection, fabrication and uses of Nickel alloys are available to you quickly from our files.

This fund of helpful information we have gathered, checked and condensed into convenient printed form. The graphs, charts and shop guides are especially useful to men handling new materials or performing unfamiliar operations . . . and to new employees. This literature is available on request.

You are also offered the assistance of our technical staff in solving material problems arising from a temporary lack of Nickel. These engineers are offering timely suggestions to many vital industries during the present emergency.

Why not drop us a card asking for list of available literature. Your request for the assistance will receive prompt attention.

# NICKEL



**THE INTERNATIONAL NICKEL COMPANY, INC.** 67 WALL STREET NEW YORK, N. Y.

vacancies created by death, (*Indicates re-election.)

The new directors are:

Production — Pacific Coast, L. L. Aubert,* Bankline Oil Company, Los Angeles, California; W. M. Keck,* Superior Oil Company, Los Angeles; Thomas A. O'Donnell,* Los Angeles; Rocky Mountain, B. B. Brooks,* Consolidated Royalty Oil Company, Casper, Wyoming; Central United States, Jake L. Hamon,* Cox & Hamon, Dallas, Texas; E. A. Landreth,* Landreth Production Corporation, Fort Worth, Texas; E. H. Moore,* E. H. Moore, Inc., Tulsa, Oklahoma; Henry L. Phillips,* Sinclair Prairie Oil Company, New York; Ralph Pryor,* Pryor & Lockhart, Wichita, Kansas; H. R. Straight,* Cities Service Oil Company, Bartlesville, Oklahoma; R. L. Wheelock,* Wheelock & Collins, Corsicana, Texas; H. C. Wiess,* Humble Oil & Refining Company, Houston, Texas; Eastern United States, P. H. Curry,* South Penn Oil Company, Pittsburgh, Pennsylvania.

Refining—Pacific Coast, A. S. Russell,* Standard Oil Company of California, San Francisco; Rocky Mountain, T. A. Dines,* Utah Oil & Refining Company, Denver, Colorado; Central United States, T. H. Barton,* Lion Oil Refining Company, El Dorado, Arkansas; Alexander Fraser,* Shell Oil Company, New York; D. J. Moran,* Continental Oil Company, Ponca City, Oklahoma; Eastern United States, Robert H. Colley,* The Atlantic Refining Company, Philadelphia, Pennsylvania; B. I. Graves, Tide Water Associated Oil Company, New York; W. S. S. Rodgers,* The Texas Company, New York.

Marketing—Pacific Coast, H. D. Collier,* Standard Oil Company of California, San Francisco; Charles S. Jones,* Richfield Oil Corporation, Los Angeles; Rocky Mountain, W. H. Gerguson,* Continental Oil Company, Denver, Colorado; Central United States, Henry M. Dawes,* The Pure Oil Company, Chicago; I. A. O'Shaughnessy,* Globe Oil & Refining Company, Minneapolis, Minnesota; E. G. Seubert,* Standard Oil Company (Indiana), Chicago; Eastern United States, W. T. Holliday,* Standard Oil Company of Ohio, Cleveland; E. W. Sinclair,* Consolidated Oil Corporation, New York.

Transportation — Ships, J. Howard Pew,* Sun Oil Company, Philadelphia; Pipe Lines, D. S. Bushnell,* Northern Group of Pipe Lines, New York.

Supply—Earl W. Miller, American Iron & Machine Works, Oklahoma City, Oklahoma; Fred F. Murray, Oil Well Supply Company, Dallas, Texas.

Natural Gas—N. C. McGowen,* Union Producing Company, Houston.

Natural Gasoline—D. E. Buchanan,* Hanlon-Buchanan, Tulsa.

At-Large—J. Frank Drake,* Gulf Oil Corporation, Pittsburgh, Pennsylvania; W. S. Farish,* Standard Oil Company of New Jersey, New York; F. F. Harris,* National Tube Company, Pittsburgh; George A. Hill, Jr.,* Houston Oil Company of Texas, Houston; A. Jacobsen,* Amerada Petroleum Corporation, New York; John M. Lovejoy,* Seaboard Oil Company of Delaware, New York; J. F. Lucey,* Lucey Petroleum Company, Dallas; R. Ogarrio, The Texas Company, New York; J. Edgar Pew,* Sun Oil Company, Philadelphia; Frank Phillips,* Phillips Petroleum Company, Bartlesville, Oklahoma; E. B. Reeser,* Barnsdall Oil Company, Tulsa; H. F. Sinclair,* Consolidated Oil Company, New York.

Messrs. Miller and Murray succeed W. M. Bovaird, of Bovaird Supply Corporation, Tulsa, and E. W. Gildart, Norvell Wilder Company, Beaumont, Texas. Graves succeeds H. R. Gallagher, and Ogarrio succeeds T. Rieber.

### General Committee

Members of the division of production elected the following general committee:

E. L. Adams, General Petroleum Corporation, Los Angeles; L. E. Barrows, The Texas Company, Houston; P. H. Bohart, Gulf Oil Corporation, Tulsa; C. F. Dimit, Phillips Petroleum Company, Bartlesville, Oklahoma; J. C. Dyer, Continental Oil Company, Ponca City, Oklahoma; R. H. Hargrove, Union Producing Company, Shreveport, Louisiana; M. J. Kirwan, Indian Territory Illuminating Oil Company, Bartlesville, Oklahoma; C. H. Kountz, Sinclair Refining Company, Independence, Kansas; Harry Leonard, Roswell, New Mexico; W. M. O'Connor, The Atlantic Refining Company, Philadelphia; B. E. Parsons, General Petroleum Corporation, Los Angeles; F. O. Prior, Stanolind Oil & Gas Company, Tulsa; D. T. Ring, Preston Oil Company, Columbus, Ohio; A. C. Rubel, Union Oil Company of California, Los Angeles; O. C. Schorp, The Carter Oil Company, Tulsa; H. M. Stalcup, Skelly Oil Company, Tulsa; R. C. Stoner, Standard Oil Company of Cali-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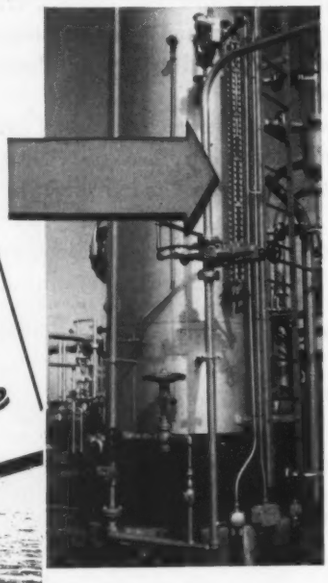
Yes, make it a Jerguson if you want a strong, sturdy

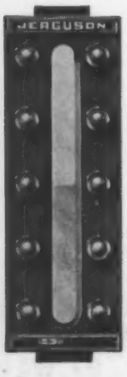
*Reflex Gage*

. . . and make it a Jerguson if you want a durable, readable

*Transparent Gage*



Reflex Gage




Transparent Gage

WOULD it interest you to know that right now we are making a large number of special gages for the Navy?

And the gages we make for service in your plant are just as sturdily and carefully made—only the design is different.

Surely if such exacting buyers as those running our first line of defense find in Jerguson the answer to their gage requirements, doesn't it stand to reason that here you will find the answer to yours?

| JERGUSON *Reflex* GAGES | JERGUSON *Transparent* GAGES |
|---|---|
| recommended for Pressures up to 3200 lbs. at 100° F., or Pressures up to 1200 lbs. at 1000° F. | recommended for Pressures up to 2000 lbs. at 100° F., or Pressures up to 600 lbs. at 1000° F. |

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fornia, San Francisco; John R. Suman, Humble Oil & Refining Company, Houston; Paul D. Torrey, Houston; and H. T. Wyatt, Shell Oil Company, Los Angeles.

**Some Appointed**

The following were appointed by President William R. Boyd, Jr., as additional members of the committee: L. L. Aubert, Bankline Oil Company, Los Angeles; E. DeGolyer, DeGolyer & MacNaughton, Dallas; O. D. Donnell, The Ohio Oil Company, Findlay, Ohio; John M. Lovejoy, Seaboard Oil Company of Delaware, New York; and J. Edgar Pew, Sun Oil Company, Philadelphia.

The Division of Refining elected the following members of its 1942 General Committee:

C. H. Barton, Tide Water Associated Oil Company, New York; W. F. Burt, Socony-Vacuum Oil Company, New York; O. L. Cordell, Bareco Oil Company, Tulsa; E. D. Cumming, Shell Oil Company, New York; A. D. David, Bradford Penn Refining Corporation, Clarendon, Pennsylvania; M. Halpern, The Texas Company, New York; J. L. Hanna, Standard Oil Company of California, San Francisco; G. W. Henneken, Standard Oil Company of Ohio, Cleveland; A. M. Kelley, Richfield Oil Corporation, Los Angeles; W. W. Lowe, Cities Service Oil Company, New York; T. M. Martin, Lion Oil Refining Company, El Dorado, Arkansas; G. G. Oberfell, Phillips Petroleum Company, Bartlesville; Walter Miller, Continental Oil Company, Ponca City; M. G. Paulus, Standard Oil Company (Indiana), Chicago; A. E. Pew, Jr., Sun Oil Company, Philadelphia; W. A. Slater, Gulf Oil Corporation, Pittsburgh; C. F. Smith, Standard Oil Company of New Jersey, New York; G. H. Taber, Jr., Sinclair Refining Company, New York; C. B. Watson, The Pure Oil Company, Chicago; and W. S. Zehrung, Pennzoil Refining Company, Oil City, Pennsylvania.

The following were appointed by President Boyd: Paul G. Blazer, Ashland Oil & Refining Company, Ashland, Kentucky; C. L. Henderson, The Vickers Petroleum Company, Wichita, Kansas; E. J. Henry, The Atlantic Refining Company, Philadelphia; R. B. Jones, Panhandle Refining Company, Wichita Falls; and W. L. Stewart, Jr., Union Oil Company, Los Angeles.

## *Dow Chemical Company To Get Chemical Award*

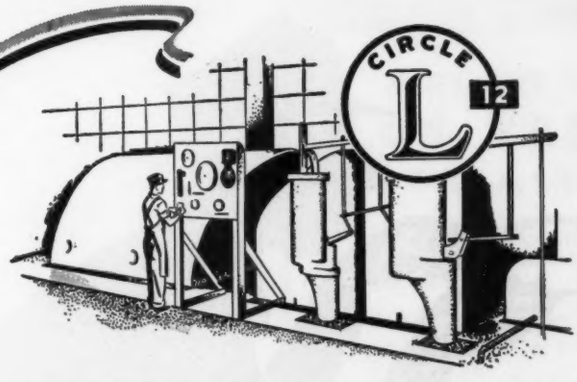
Dow Chemical Company, Midland, Michigan, will receive the 1941 award for chemical engineering achievement. The award is made each year by Chemical and Metallurgical Engineering on recommendations of a committee of leading scientists in American universities. Its chairman is Alfred H. White, head of the department of chemical and metallurgical engineering at the University of Michigan.

Presentation will be made December 2 at the dinner in connection with the eighteenth national exposition of the Chemical Industries in New York. The award is based on accomplishments of the company in the extraction of metallic magnesium from sea water.

The company is operating its extraction plant at Freeport, Texas, where 300,000,000 gallons of sea water are processed daily to extract 100,000 pounds of metal as well as bromine, which goes into the manufacture of ethyl fluid.


SYMBOLS of DEFENSE

**MEN from the oil fields of Texas are wearing once more the blue arrowhead of the AEF's 36TH Division. In World War I, this Division included National Guardsmen from Oklahoma as well as from Texas and its combat record reflects the best fighting traditions of the rugged Southwest. Furious assaults by the 36TH vitally assisted the French army to advance at a critical period in the Meuse-Argonne operations. Casualties totalled 2,584. Today, the men of Texas wear the blue arrowhead as one of the proudest battle emblems of the democracy they are prepared to guard against any threat.**




**PROUD EMBLEM in industry's defense campaign is Circle Ⓛ 12—symbol for Lebanon's 12% to 14% alloy. Its characteristics fit it especially for the handling of hot oil and high temperature steam. Circle Ⓛ 12 is one of the Lebanon alloys which, throughout the years, has made possible changes in methods and practice of far reaching economic value. One or more of these alloys may solve production problems for you. Consult a Lebanon metallurgist.**

**LEBANON STEEL FOUNDRY • LEBANON, PA.**

ORIGINAL AMERICAN LICENSEE GEORGE FISCHER (SWISS CHAMOTTE) METHOD

**LEBANON *Stainless and Special Alloy* STEEL CASTINGS**

# Washington Roundup

Distribution of the 5,846,000 tons of steel for the petroleum industry will be handled through the office of the Petroleum Coordinator. This total allocation, of which 647,000 tons is for refining, was made in Mid-November by SPAB. The allocation system was adopted by the Office of Supply Priorities and Allocations Board the second week in November.

Under the new system, OPM in cooperation with the industries, will ascertain how much of the various materials each industry needs and, in cooperation with SPAB, will allocate to each that proportion of its needs sufficient to enable the filling of essential orders.

In the case of the oil industry, the allocation for steel will be turned over to the coordinator, who then will designate where it shall go and how it shall be used.

The industry, normally the second largest consumer of steel (following transportation, including railroads and automobiles) is, under present emergency conditions, the fourth largest user, being outranked by construction, transportation and machinery.

For 1942 operations, it is estimated by the coordinator's office, the industry will require 5,846,000 tons of steel to meet the demands of the defense program. This includes 3,175,000 tons for the production branch, on the basis of more than 30,000 wells; 1,843,000 tons for transportation—pipe lines, tank cars, tank trucks, etc.; 647,000 tons for refining, including aviation gasoline facilities, and 181,000 tons for marketing.

Included in the 3,175,000 tons for the production branch is 1,817,000 tons of tubular goods, of which the industry is the nation's biggest user, and also probably the largest permanent user of steel by reason of the fact that much of the casing is necessarily cemented in the ground and is thereafter irrecoverable.

Regulations of the OPM with respect to priorities for repair, maintenance and operating supplies, were amended November 10 to bring natural gas, and hydrocarbons associated with petroleum, under the terms of the preference rating order, and extended it to the transportation as well as the production of those items.

OPM officials explained that this means that pipe lines, railroads and truck fleets engaged in moving the products of the petroleum industry may now apply the A-10 rating to the acquisition of the necessary repair and maintenance parts and operating supplies.

Another amendment extends the priorities to those using tools or equipment to repair or maintain the property of other producers, thus extending priority assistance to independent contractors and others, such as machine and repair shops.

At the same time, OPM eliminated its previous restriction against the replacement of existing equipment by improved equipment and prohibiting replacements unless the existing installation is beyond repair. It was explained that it has been found impossible, and in many cases undesirable, to require replacement with equipment exactly like the old, since this frequently held the producer to the use of antiquated equipment, and sometimes made it impossible for him to obtain any replacement equipment at all.

Charging that certain suppliers have made misleading statements to their customers regarding the operation of Preference Rating Order P-22, issued by OPM to facilitate the securing of repair and maintenance material, "in an effort to induce their customers to use the rating in obtaining materials," the legal division of OPC on November 12 issued an explanatory statement on the purpose and use of the priorities accorded by the order.

The actual user of the equipment ordered under P-22 is the only person entitled to initiate the A-10 rating which is provided, it was pointed out, and, the division warned, "it follows therefore that such person will be the one held primarily liable for any misuse of the order."

"To operators in the industry," it was explained, "this means that they must be extremely careful to see that they comply in every respect with the provisions of P-22 before endorsing the certification which permits them to apply the A-10 rating.

"It should be emphasized that in applying the A-10 rating, it is the purpose for which equipment is to be used, not the equipment itself, which is determinative of the right of any operator to apply


Visibility
PLUS UNIFORM ACCURACY

Have you ever had a gauge glass break almost immediately after you installed it? If you have, it was probably due to installation strains which are the result of a slightly oversized glass.

To overcome these strains, PYREX and Corning Gauge Glasses are machine drawn to uniform accuracy.

In addition, PYREX Broad Red Line Gauge Glasses have these outstanding economy features: Resistance to the chemical attack of hot water and steam, resistance to heat and cold shocks, and visibility from greater distances. Ask your dealer for complete details. PYREX and Corning Gauge Glasses are stocked by leading steam and mill supply houses.

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CORNING Glass Works Corning, New York

Pyrex Gauge Glasses

the A-10 rating. Thus, although many types of equipment can be obtained under P-22, only such equipment can properly be obtained under the order as is to be used for 'maintenance,' 'repair,' and 'operating supplies' as defined therein. Any use of the order to obtain equipment for other purposes is a violation of the policy behind the order, as well as a violation of the specific provisions incorporated therein.

"It is important that operators should note in this connection that any person who applies an A-10 rating assigned by the order in wilful violation of the terms and provisions of the order, or who wilfully falsifies any records required to be kept by the order, or who obtains delivery of material by means of a material and wilful misstatement may be forbidden to apply further the A-10 rating. In addition, such an operator may be prohibited from obtaining further deliveries of material under allocation, and may be deprived of any further priority assistance. The Director of Priorities is also given power to take any other action deemed appropriate in the circumstances of the case, including the making of a recommendation for prosecution under Section 35A of the Criminal Code (18 U.S.C. 80)."

In determining the proper purposes for which materials may be obtained, it was explained, "operating supplies" means only material which is essential to the operation of a user's business and which is consumed in the course of such business.

"Thus," the division declared, "contrary to the impression created by certain suppliers in circular letters sent to the trade, desks, file cabinets, typewriters, and other office accessories ordinarily thought of as a capital outlay cannot be obtained under the A-10 rating assigned by Preference Rating Order P-22, unless specifically within the 'maintenance' or 'repair' provisions.

"It should also be noted that 'operating supplies' do not include material which is to be physically incorporated in whole or in part into any product of the user, or into any material which the user distributes to or stores, transports, or services for another person. The terms 'maintenance,' 'repair,' and 'operating supplies' do not include material which is to be used for additions to, or expansion of, a user's property or equipment, nor do these terms include any material which is of a type not previously carried on a user's book under 'maintenance,' 'repairs,' 'operating supplies,' or the equivalent."

### Investigation

Broadening of the authority of the special Senate committee which recently investigated the East Coast oil shortage, to include a study of the situation with respect to solid fuels was asked of the Senate, November 10, by Senator Francis Maloney of Connecticut, chairman of the group.

Further extension of the investigation to take in power also was immediately sought by Senator McKellar of Tennessee, one of the Southeastern States in which compulsory curtailment of the use of electricity is threatened.

Maloney submitted his request immediately following the disclosure that President Roosevelt had made Coordinator Ickes responsible for solid fuels as well as oil. There is at present no need for a further investigation of the oil situation, the senator said, but the


# KNOCKS DOWN both dangerous fires!

SUPPOSE a paint dip-tank bursts into flame? What if an electric motor catches fire? Can your extinguishers handle those blazes?

These two types — electrical and flammable liquid fires — are hazards which threaten 19 out of 20 industrial plants. They are the blazes which LUX extinguishers are engineered to fight. Without the ability to smother these fires you simply haven't got fire protection.

LUX equipment hits these blazes in a hard-hitting blizzard of carbon dioxide snow-and-gas, lightning-fast extinguishing agent. Use LUX portables for ordinary hazards. Install built-in LUX systems for the intense, concentrated hazards, like storage spaces, tanks or kettles for flammable liquids and solvents.

LUX protection means *added* protection. It means *plus* values in your plant's day-and-night safety.

## HERE ARE THE *PLUS VALUES* IN FIRE-FIGHTING

1. LUX carbon dioxide gas is one of the fastest known extinguishing agents.
2. LUX extinguishers are effective on both electrical and flammable liquid fires.
3. LUX gas is clean, non-damaging, non-contaminating, non-toxic.
4. *45,000% expansion* drives LUX gas throughout fire area, despite obstructions.
5. Annual recharging is not necessary with LUX. Simply weigh periodically.
6. LUX service depots are maintained in principal cities.

LUX SNUFFS OUT FIRE

**Walter Kidde & Company**
Incorporated
**1117 West Street, Bloomfield, N. J.**

committee should "be prepared for any fuel emergency."

"In connection with the possible danger of a further oil shortage," he told the Senate, "I am sure that careful plans will be made to meet any later emergency.

"New tankers are now being rapidly completed, and the tanker fleet under American jurisdiction is growing fast. This encouraging condition, with the chance for the organization of tank-truck carrying facilities, and the other facilities which could be made available, would enable us to ward off the dangers which might come with the intensity of the wars abroad."

Hearings on the production of petroleum and natural gas on the public lands, which have already been held in Denver, will shortly be moved to Washington, it was disclosed by Senator Joseph C. O'Mahoney of Wyoming, chairman of a Public Lands subcommittee in charge of the inquiry. Because of the fact that the Maloney investigation goes further than that authorized by his committee, O'Mahoney suggested the former should be extended so as to make sure that the question of production on the public lands is included in any survey which may be made of the general situation.

### Pipe Line

Application for priority rating for some 85,000 tons of steel needed for the construction of its proposed Wichita Falls, Texas - Savanah, Georgia, crude line has been filed with the Supply Priorities and Allocations Board by Trans-American Pipeline Corporation.

The application was submitted following a tacit invitation by SPAB in its decision refusing priorities to the projected Texas-New York line, in which it said consideration would be given to proposals for the construction of short, inexpensive pipe lines to link sources of supply with markets.

The announced plans of TAPCO call for a 10¾-inch line from Wichita Falls to the east Texas line, and a 12¾-inch line to Savannah, the 1050 miles of pipe being estimated to cost $12,637,000. Also required would be six 1200-horsepower pumping stations and 20 2400-horsepower stations. Construction of underground storage for 3,000,000 barrels at Savannah would cost $1,500,000.

Company officials claim the project has been found by the coordinator's office to have merit, although OPC has not yet taken any formal action, and that the Navy Department has evinced interest, particularly if the line were extended to Charleston, South Carolina, where there is a naval base.

The proposed line has been given the consideration of the Navy Department, and in a departmental report to the office of the Secretary it was held that the Texas-Georgia project was desirable although, it was added, "this line does not deliver the oil where it would be most convenient so far as the Navy is concerned."

However, it was commented, factors in favor of the line are the short time—six months—which would be required for its construction, the comparatively small amount of steel which would be required and the fact that it would be a common carrier.

"The oil coordinator is possibly not in favor of the line because it does offer an inducement to small independent oil companies to develop these reserves," the report suggested in referring to the fact that it would traverse the territory in which is located 22 percent of the country's reserves.

"Provided either OPM or the oil coordinator asks for our opinion on this matter," the author of the report concluded, "I would, personally, be in favor of approving the project," assuming that all the information submitted presents a "fair picture." "However, as a matter of policy the Chief of Naval Operations does not recommend approval of any commercial project which does not directly affect the Navy.

## *Perkin Medal to Martin H. Ittner*

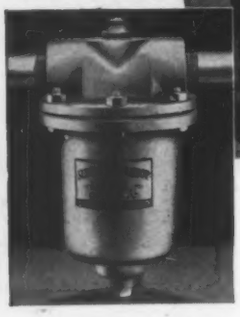
Dr. Martin H. Ittner, who is in charge of research for Colgate-Palmolive-Peet Company, has been elected to receive the Perkin Medal of the Society of Chemical Industry for 1942. The medal is awarded annually for outstanding work in applied chemistry.

The medal will be presented January 9 at a meeting in the Chemists' Club, New York.

## *Moorhead Member of Arbitration Group*

J. E. Moorhead, executive manager of Pennsylvania Grade Crude Oil Association, Oil City, Pennsylvania, has been named to the national panel of arbitrators of the American Arbitration Association.


**WHY DO YOU PUT UP WITH DETOUR PIPING**



● Why do you continue to put up with complicated, "detour" piping when simplified piping costs no more, looks neater, saves installation time and gives long service life?

Anderson Super-Silvertop, the inverted bucket trap with simplified piping, is noted for neat, clean-cut installations—straight-in-line piping. It averages more condensate capacity because of larger bucket and longer lever arm. Super-Silvertops are backed by 55 years of steam trap manufacturing experience. Regular inspection is much faster because traps are inspected without disturbing pipe connections. Also, nationwide distribution and experienced field men are assurance of prompt attention and help on trapping problems.

Think about this engineered steam trap—then ask yourself—"Why do I put up with detour piping?" Then decide to do something about it. Send for your copy of "How To Choose A Steam Trap." It's a helpful book of charts, tables and useful information that you can use almost every day. Get your copy and find out more about Anderson Super-Silvertops and simplified piping. Write today.

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**Super-Silvertop**
**STEAM TRAPS**

## *Officials Named for Petroleum Section*

Officials and committee chairman for the petroleum section of the National Safety Council were elected at the meeting of the National Safety Congress and Exposition in Chicago, October 6 to 10 as follows:

General Chairman—F. R. McLean, White Star-Ohio Division, Socony-Vacuum Oil Company, Detroit.

Vice Chairman for Production—H. T. Markee, Phillips Petroleum Company, Bartlesville.

Vice Chairman for Pipe Lines—J. L. Manes, Sun Oil Company, Dallas.

Vice Chairman for Manufacturing—J. Howard Myers, The Atlantic Refining Company, Philadelphia.

Vice Chairman for Marketing—J. J. Reilly, Tide Water Associated Oil Company, Boston.

News Letter Editor—J. B. Harris, Arkansas Natural Gas Corporation, Shreveport.

Engineering Committee Chairman—Crymes Pittman, United Gas Pipe Line Company, Shreveport.

Health Committee Chairman—Dr. V. M. Brian, The Texas Company, Lawrenceville, Ill.

Industrial Data Sheet Committee Chairman—J. L. Risinger, Socony-Vacuum Oil Company, New York.

Program Committee—H. T. Markee, Phillips Petroleum Company, Bartlesville; J. L. Manes, Sun Oil Company, Dallas; J. Howard Myers, The Atlantic Refining Company, Philadelphia, and J. J. Reilly, Tide Water Associated Oil Company, Boston.

Publicity Committee Chairman—R. S. Huffman, Oklahoma Natural Gas Company, Tulsa.

Visual Education Committee Chairman—F. M. Russell, Standard Oil Company of California, San Francisco.

Atlantic Division Chairman—A. J. Gorand, Sun Oil Company, Marcus Hook, Pa.

Great Lakes Division Chairman—Alexis de Tarnowsky, The Pure Oil Company, Chicago.

Gulf Division Chairman—Thomas F. Brown, Gulf Oil Corporation, Houston.

Mid-Continent Division Chairman—C. L. Barrett, Gulf Oil Corporation, Tulsa.

New England Division Chairman—Eugene Swanson, Colonial Beacon Oil Company, Everett, Mass.

Pacific Coast Division Chairman—W. E. Lovejoy, Standard Oil Company of California, Taft.

## *Natural Gas and Gasoline Coordination Discussed*

Declaring that the natural gas and natural gasoline supplies of the country must be coordinated into the national defense program in the same manner as have those of the oil industry, Robert E. Allen, director of production in the oil coordinator's office, told representatives of the two industries October 23 that a natural gas and natural gasoline industry committee will be set up in each of the 5 petroleum districts in the immediate future.

Speaking at a conference in New York called by the coordinator to discuss the defense efforts of the two industries, Allen explained that the chairmen of the committees will serve as members of the already-existing general committees, but the natural gas and gasoline industries will


# Which Would You Rather Buy ?

## A New Valve — or — Renewable Seats

**Thousands of dollars worth of brass gate valves are consigned to the scrap heap every year when they are as good as new except for a leaky seat.**

**But it's different with Fairbanks *Renewable* Valves. They eliminate that waste.**

**Instead of throwing away a Fairbanks "Renewable" Bronze Gate Valve when the seat rings finally become worn, you can quickly slip in new ones—and the valve is as good as new at about 10% of what a new valve would cost. This takes only a few minutes —just long enough to unscrew the bonnet and slip in a new ring. And that can be done without removing the valve from the pipe line.**

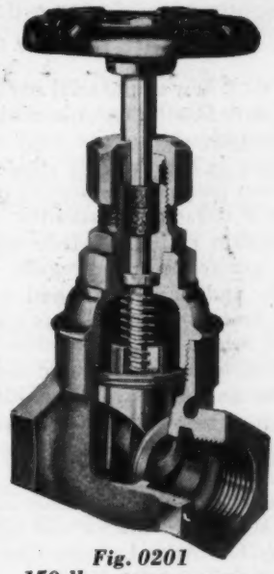

***Fig. 0201***
***150 lbs. steam pressure***

**Contrast this quick, easy and inexpensive renewal with non-renewable valves that have the seats cast integral with the body.**

**Quick renewal is important when shutting off the steam for a long time means the shutdown of machinery for the same period.**

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**Factories: Binghamton, N. Y., Rome, Ga.**

**Fairbanks Renewable Valves**

be "in no sense or in nowise subservient to these petroleum industry groups."

Each committee will consist of 8 members, who will be nominated by the industries, familiar with the functional divisions of the two branches.

Meanwhile, because of the fact that there are several federal agencies having responsibilities and duties with respect to the natural gas and natural gasoline industries, the coordinator's office will hold a conference with those agencies to draft plans for the coordination of all federal activities affecting the two industries.

Allen told the conference that there are a number of problems of general character which it will be necessary immediately to deal with.

"Production of natural gas must be so arranged as to insure the maintenance of adequate supply and the conservation of an invaluable natural resource," he said. "Cycling or repressuring programs must be developed for many of the condensate or distillate fields. A good deal of thought must be given to the best utilization of natural gas and natural gasoline both by processes, regions and industries. We must particularly stress the problem of the production and utilization of iso-pentanes, butanes and iso-butanes for the manufacture of aviation gasoline. We must maintain our transportation facilities at peaks of efficiency; perhaps new lines must be built in various sections of the country, certainly we must devise plans to more efficiently use our existing facilities.

"We must face the very tough problem of maintaining a constant steady supply of natural gas to industries that are truly producing for defense. And fundamental to all of your deliberations you must recognize that the materials and supplies needed to keep your industries functioning are no longer readily available in large quantities, but that the imposition of priorities upon the basic materials or finished products you need and use have raised serious problems of maintenance, repair and expansion."


STEEL STACKS LINED QUICKLY
... AT LOW COST!

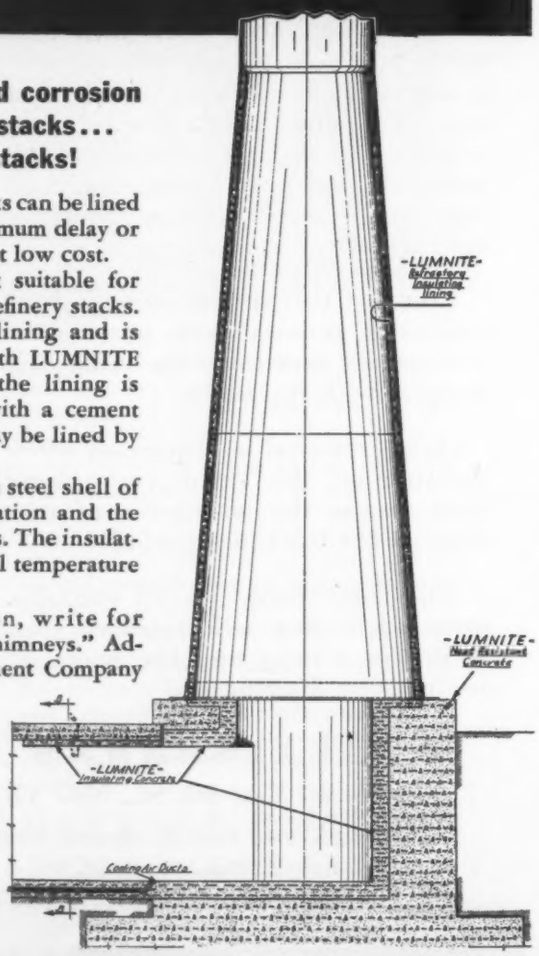
**Protection from heat and corrosion means new life for old stacks... longer life for new stacks!**

YOUR new or old steel stacks can be lined with LUMNITE with minimum delay or interruption to service—and at low cost.

Here is a lining 2½" thick suitable for highest temperatures met in refinery stacks. It is a refractory insulating lining and is corrosion resistant. Made with LUMNITE and a refractory aggregate, the lining is easily and quickly applied with a cement gun. Small stacks and flues may be lined by hand before or after erection.

LUMNITE linings guard the steel shell of stacks and flues against oxidation and the attack of sulphurous flue gases. The insulating property keeps down shell temperature and improves draft.

For detailed information, write for "LUMNITE in Stacks and Chimneys." Address The Atlas Lumnite Cement Company (United States Steel Corporation Subsidiary), Dept. R-14, Chrysler Bldg., New York City.




Cross-section of steel stack, showing Lumnite protective lining, and a duct installation below built of Lumnite heat-resistant concrete lined with Lumnite insulating concrete.

LUMNITE FOR REFRACTORY CONCRETE


## *New Laboratory for API Research Projects*

A new laboratory for materials testing will be included in the building to be constructed in Washington for the National Bureau of Standards. Here research workers will carry on the work of isolating and identifying hydrocarbons in petroleum, sponsored jointly by the bureau and the American Petroleum Institute as API Project 6, under the supervision of Frederick D. Rossini.

The project was started 14 years ago and through it 62 hydrocarbons in the gasoline-kerosene fractions of petroleum have been identified as well as many homogeneous fractions from lubricating oils. Findings of the research have been made available by publication of 79 papers. The project is one of several started by the American Petroleum Institute after 1926 through funds made available from the late John D. Rockefeller and the Universal Oil Products Company, Chicago.

The work embodies fundamental research in broadening the scope of petroleum's service to mankind and is designed to lay the groundwork for studies and experiments from which may come a growing list of essential products which in the future may be obtained more readily and economically from petroleum rather than from present sources.

## *Wilson Addresses Houston Chemists*

Dr. Robert E. Wilson, president of Pan American Petroleum and Transport Company, New York, addressed the Houston chapter of the American Institute of Chemical Engineers, October 23, on "Refinery Gases as Chemical Raw Materials." Dr. Wilson, former petroleum adviser to the Office of Production Management, was accompanied on a tour of Pan American's properties in Texas by E. G. McKeever, first vice president, and J. A. Carroll, Jr., vice president and treasurer.

## *Truck Discharge Systems*

Results of the investigations carried on by Professor Lewis H. Kessler at the University of Wisconsin under a fellowship set by the National Truck Tank Association have been published in a "Manual of Design Data for Truck-Tank Discharge Systems." It is a loose-leaf book of 168 pages, price $10, available through the association, 120 South LaSalle Street, Chicago.

At the hydraulics laboratory of the University of Wisconsin more than 4500 tests were made on 120 pieces of equipment and the manual is a tabular and graphic summary of the tests which complete hydraulic characteristics of the equipment.

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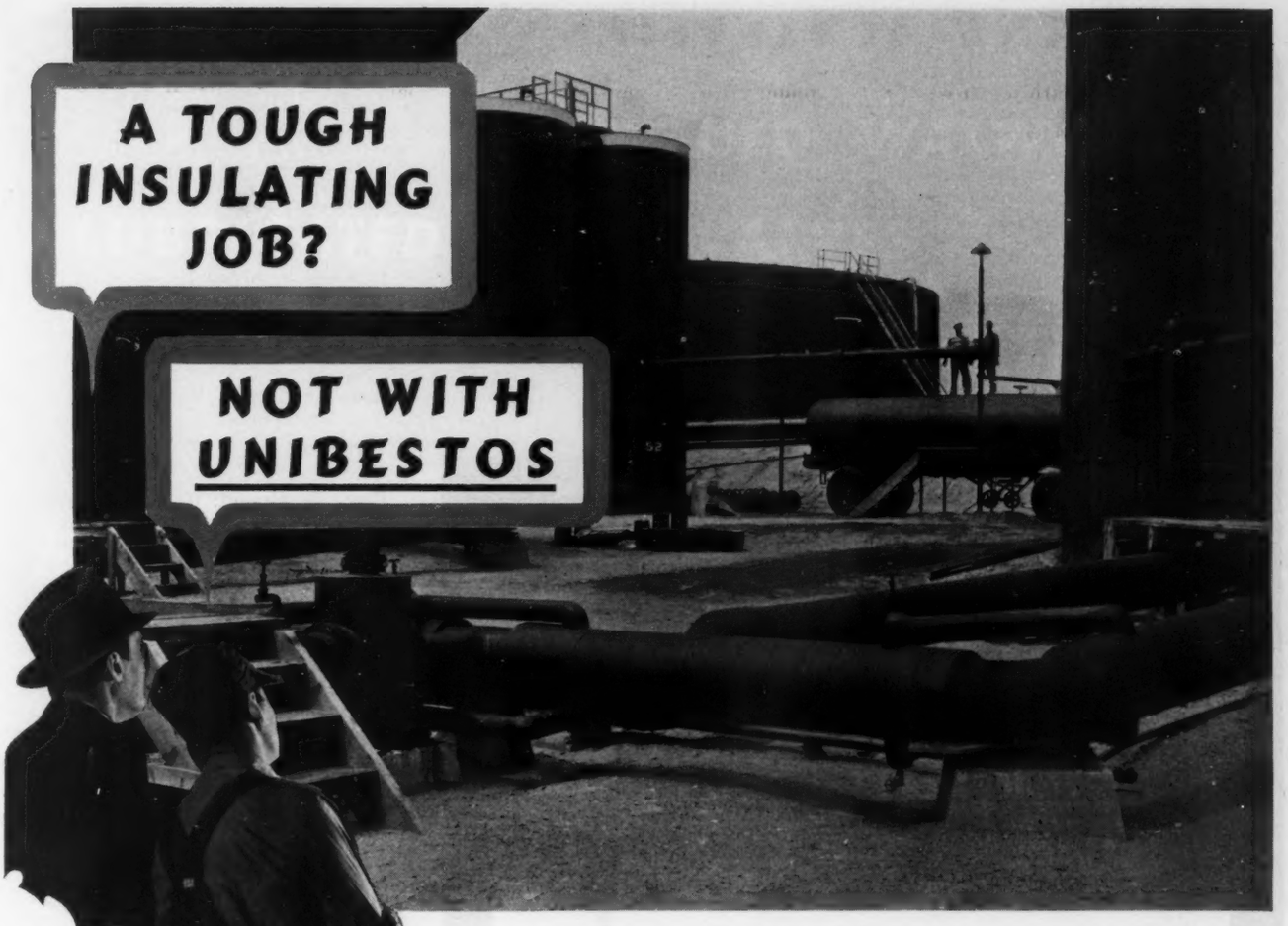
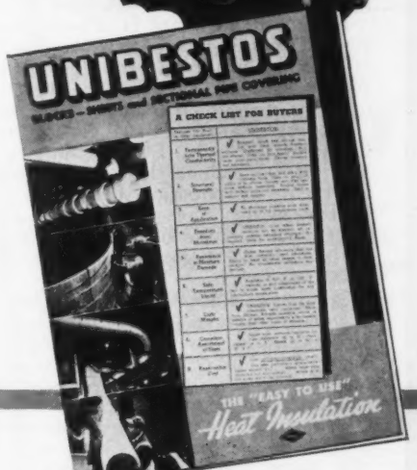
## NOT WITH UNIBESTOS



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UNIBESTOS has higher thermal efficiency than the most commonly used insulations. Cost, *including installation*, often runs less. It is offered in a complete range of sizes: sectional insulation for all pipe diameters up to 36", thicknesses up to 5". Sheets up to 36" x 36" x 5". Available in 750° F. or 1200° F. material, or any combination of the two in *single layer* construction for any intermediate temperature. This means that you can have ONE insulation, in single layer, for use on ALL temperatures up to 1200° F.

WRITE for your copy of this concise new 4-page informative bulletin containing all data needed for figuring most commonly encountered insulation jobs. Complete with tables on dimensions, temperatures, heat losses, list prices, etc.

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# ▼ PLANT ACTIVITIES ▼

Plant construction within the refining division of the petroleum industry last month gained the added stimulant of tripling its capacity to produce 100-octane aviation gasoline. After reviewing surveys of the five refining committees of the nation, Harold L. Ickes, Petroleum Coordinator, asked that the output of this product be increased to 120,000 barrels daily by the end of 1942. Present output is in excess of 40,000 barrels daily.

Priority ratings already have been granted for the following plants as part of the program:

Union Oil Company, Wilmington, isopentane; Shell Oil Company, Wilmington, isopentane; Shell Oil Company, Houston, isopentane - hydrocodimer; Shell Oil Company, Wood River, isopentane; Phillips Petroleum Company, Borger, 100-octane; Gulf Refining Company, Port Arthur, 100-octane base stock; LaGloria Corporation, Corpus Christi, isobutane.

Along with the special units for blending material, other construction due to follow will be the addition of cracking units, both thermal and catalytic, which will give both bases of alkylation and cracked naphthas for base stock in 100-octane aviation gasoline.


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TREATS CRACKED OR POLYMER GASOLINES EQUALLY WELL

Whether the gasoline treated is from a cracking or polymerization unit—the result is the same—a quality, low gum content motor fuel—produced with low treating costs.

Units are simple in design—operating and maintenance costs are exceptionally low.

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**Isobutane:** The need for isobutane from natural gas resulted in revival of the recycling project for the Katy field, near Houston. Humble Oil & Refining Company and others have been granted priority rating of A-1-C from OPM and application has been made to the Texas Railroad Commission, following unitization of acreage. The plant will process 200,000,000 cubic feet of gas daily and the plant is scheduled to cost $2,500,000. Total butanes will be fractionated to recover isobutane.

**Plant Leased:** The topping plant of Petroleum Refining Company, Shelby, Montana, has been leased to Frank V. Long, president and general manager of the company.

**Gasoline Plant:** Warren Petroleum Corporation, Tulsa, announced plans for construction of a natural gasoline plant in the Cumberland field, Oklahoma, where 41 wells are producing.

**Plant Purchased:** Included in properties bought by Stanolind Oil & Gas Company, Tulsa, from Coronado Corporation, Dallas, was the recycling plant at LaRosa. The unit processes 60,000,000 feet of distillate-bearing gas daily. The purchase included producing and royalty properties and the transaction involved more than $5,000,000.

**Aviation Gasoline:** Gulf Refining Company will add a cracking unit at Port Arthur as well as an isooctane plant. The two will increase 100-octane aviation gasoline of the large Texas plant from 1500 to 4000 barrels daily.

**Cycling Plant:** Preliminary plans for a cycling plant of the absorption type for the Grapeland field, Houston County, Texas, were announced in November by Geier-Jackson Recycling Company. The unit will process 50,000,000 cubic feet daily of distillate-bearing gas. Dry gas will be returned to the sand.

**Buying Plant:** Paul H. Pewitt, Longview, Texas, is negotiating for purchase of the cycling plant of Portex, Inc., Shelby County, Texas. The field has only three wells on 1600 acres of leases.

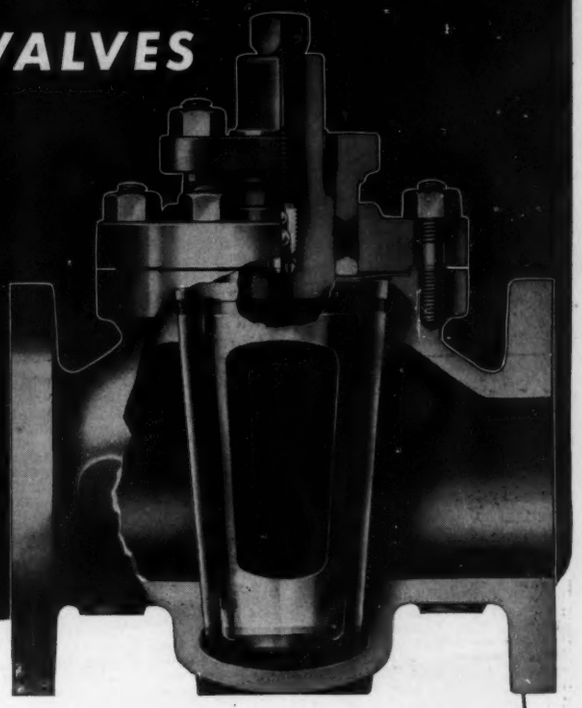
**Moving Canadian Plant:** Vermilion Consolidated Oils, Ltd., is moving its plant from Kindersley to Vermilion, where it will operate on crude from nearby fields. The plant was built in 1939 to run crude oil from the United States but operations were shut down due to the war.

**Synthetic Rubber:** Hycar Chemical Company, Akron, Ohio, has started construction of a new plant near Louisville, Kentucky. The concern, which is owned by The B. F. Goodrich Company and Phillips Petroleum Company, recently changed its name from Hydrocarbon Chemical and Rubber Company. The new plant will increase output of the concern to four times the output of the nation last year. The new plant will produce 10,000 long tons each year and expansion at the Akron plant will increase output there to 7000 long tons annually.

## *On Corrosion Committee*

F. L. Newcomb of Standard Oil Development Company, Elizabeth, New Jersey, has been named as a member of the committee on Corrosion of Refinery Equipment of the American Petroleum Institute. He succeeds R. L. Duff, who resigned. The appointment was made by Dr. T. G. Delbridge, The Atlantic Refining Company, chairman of the central committee on Refinery Technology.

# WHEN SHOULD WALWORTH LUBRICATED PLUG VALVES BE USED?



## WHEN

When the conventional type of valve does not give satisfactory service, the solution is generally to be found in the Walworth Lubricated Plug Valve.

## WHERE

Where full direct port opening with one-quarter turn and a positive, tight shut-off is desired, use Walworth Lubricated Plug Valves.

## WHY

Because the Walworth Lubricated Plug Valve is a smooth-turning, easy to operate valve that remains completely sealed against leakage in either the open or closed position. It has demonstrated its ability to give a tight shut-off on substances difficult to hold, and where leaks are hazardous or costly.

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*The abstracts here presented are selected from the current literature of science and technology to afford reference to fundamental information not easily available to all readers. Abstracts of articles appearing in readily obtainable trade journals are not included.*

*Photostat copies of original articles will be supplied at cost by the Leslie Laboratories. Complete or limited bibliographies covering special topics by title, by abstracts, or in complete manuscript, will also be prepared and furnished at reasonable cost by the Laboratories.*

## Fundamental Physical and Chemical Data

**The Heat Capacity of Gaseous Paraffin Hydrocarbons, Including Experimental Values for n-Pentane and 2,2-Dimethylbutane,** K. S. PITZER, *Jour. Amer. Chem. Soc.* **63** (1941) pp. 2413-18.

A calorimeter of the flow type that measures both the heat capacity of the gas and the heat of vaporization of the liquid is described. The liquid was continuously vaporized by electrical heat, and, after passing the heat capacity unit, the vapor was condensed, brought to the boiling point, and returned to the vaporizing unit. The rate of heat flow, and thereby the heat of vaporization, was measured by diverting the gas flow into a separate condenser and sample bulb for an accurately timed interval. The heat capacity unit consisted of a thermally insulated tube containing in order, a platinum resistance thermometer, an electrical heater, and two more platinum resistance themometers. Corrections for heat loss along the tube were made, either on the basis of the difference between the last two thermometers, or on the variation of apparent heat capacity with rate of flow. Results obtained agree with the statistically calculated heat capacity of carbon tethachloride vapor. Measurements are reported for the heat of vaporization of n-pentane and 2,2-dimethylbutane, and for the heat capacities of these vapors from their boiling points to about 450° K. Values in the literature for n-pentane agree with the results obtanied for the heat of vaporization, but not for the vapor heat capacities. The two previously statistically calculated values for n-pentane are compared with the heat capacity data obtained. It was found that the 3600 calories per mole potential barrier to internal rotation is much more nearly correct than the 16,000 calorie value proposed by Messerly and Kennedy. Similarly, for n-butane, the true barrier is probably much nearer 3600 than the 30,000 value proposed by Aston and Messerly. It is found that the equation $C_p = 5.65n - 0.62 + t(0.0111n + 0.0158)$ fits the available data for all gaseous paraffins above ethane, both normal and branched. This equation should be useful for many practical calculations. In this equation, n is the number of carbon atoms, and t is the temperature in ° C.

**The Thermodynamics of Branched-Chain Paraffins. The Heat Capacity, Heat of Fusion and Vaporization, and Entropy of 2,3,4-Trimethylpentane,** K. S. PITZER AND D. W. SCOTT, *Jour. Amer. Chem. Soc.* **63** (1941) pp. 2419-22.

The investigation reported is a continuation of the program of developing general formulas for the thermodynamic properties of the gaseous paraffin hydrocarbons. The following results were obtained for 2,3,4-trimethylpentane, melting point, 163.63 ± 0.1° K; heat of fusion, 2215 ± 5 cal. per mole; heat of vaporization, 7810 ± 30 cal. per mole; entropy of liquid at 298.1° K, 78.71 ± 0.2 cal. per degree mole; entropy of the real gas at the boiling point 386.5° K, 115.78 ± 0.3 cal. per degree mole. Heat capacities of the solid, liquid, or gas are given covering most of the range 15 to 417° K. The entropy is shown to be in reasonable agreement with the value calculated from approximate statistical formulas. A simple semi-empirical formula is suggested for calculating the entropies of the heavier branched-chain paraffins. It is shown to give results in agreement with the available experimental data, and with the values calculated from the more complex statistical formulas. The combination of this formula for entropies with the simple formula for heat capacities, should constitute a convenient method for thermodynamic calculations.

**P-V-T Relations for Saturated Liquids,** H. P. MEISSNER AND O. H. PADDISON, JR., *Ind. & Eng. Chem.* **33** (1941) pp. 1189-91.

The engineer frequently faces the problem of predicting liquid densities. During recent years it has been demonstrated that the reduced P-V-T relations for gases and vapors conform closely to a generalized graphical equation of state. It seemed possible to the authors that saturated liquid, being in equilibrium with saturated vapor, might follow a relationship similar to the one that applies to the vapors, namely PV = uRT, in which u is a unique function of the reduced temperature and pressure. The P-V-T data for pure saturated liquids were studied, and it was discovered that such a relationship exists. Charts are presented in the article that make it possible to predict liquid densities with reasonable accuracy if the critical temperature, critical pressure, and some vapor pressure data are available for the liquid in question. These charts can be secured at cost from the Chemical Engineering Department at the Massachusetts Institute of Technology. The relationship developed applies only to saturated liquids, and not to liquids under

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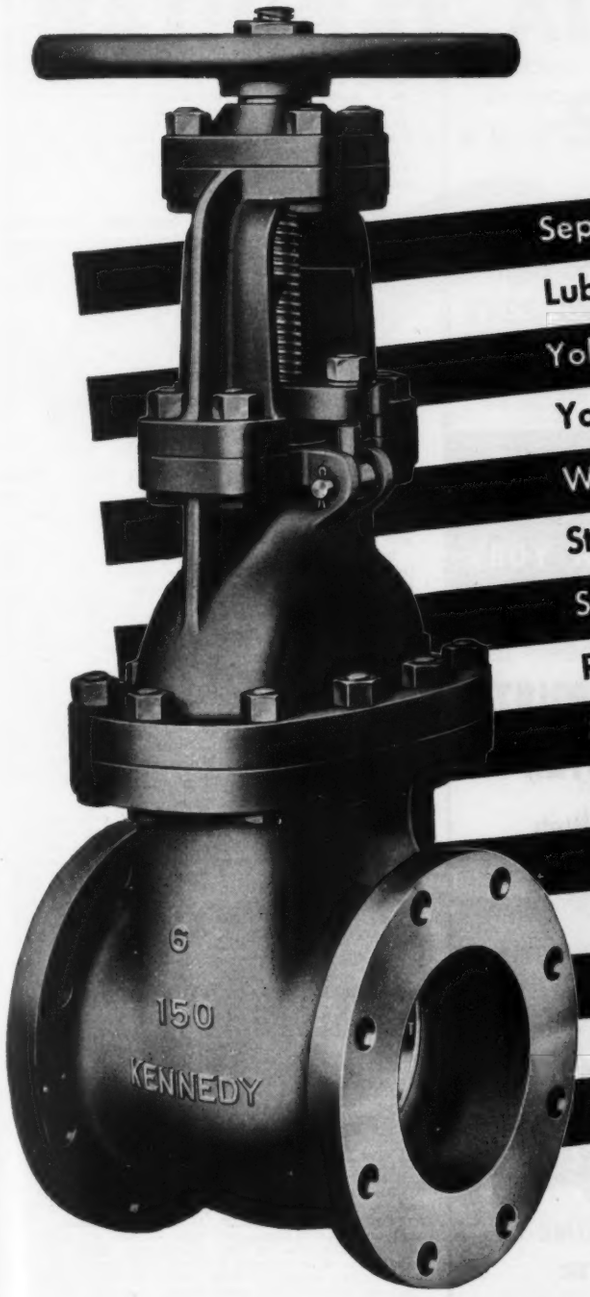
# Only the KENNEDY Iron-Body Wedge Gate Valve has ALL these features . . .




- Separate yoke cap
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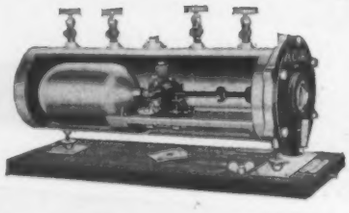

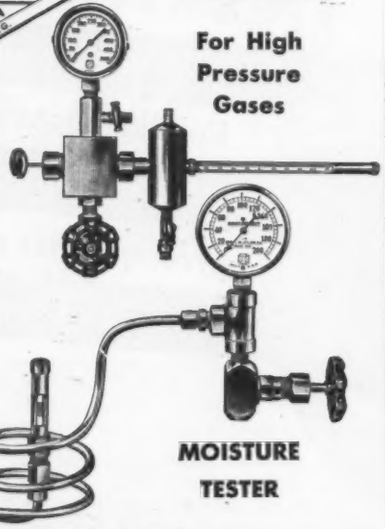

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pressures greater than their vapor pressures at any given temperature. However, as a first approximation, it can be assumed that the volume of the liquid under moderately high pressure equals the volume this liquid would occupy at the same temperature but under its saturation pressure. Work is continuing on the P-V-T relationships of liquids under pressures greater than their saturation pressures, and on liquid mixtures.

**Molal Volume Relationships Among Aliphatic Hydrocarbons at Their Boiling Points,** G. EGLOFF AND R. C. KUDER, *Jour. Inst. Petr.* **27** (1941) pp. 260-74.

By means of equations of the type $V = a(n + 4.4)^c + K$ the molal volumes of 63 aliphatic hydrocarbons arranged in 14 different homologous series at their boiling points have been correlated with the number of carbon atoms in the molecule. The mean deviation of the calculated from observed values is 0.39 ml./mol. By means of equations of the type $\log (V - k) = At + B'$ the boiling-point molal volumes of 43 aliphatic hydrocarbons in 9 homologous series have been correlated with the boiling points, with a mean deviation of 0.62 ml./mol. The effect of the structure of the hydrocarbon molecule on the molal volume at the boiling point is discussed, and comparisons are made with the effect at 20° C.

**The Densities and Surface Tensions of cis- and trans-Decahydronaphthalene between —30 and 180°,** W. F. SEYER AND C. H. DAVENPORT, *Jour. Amer. Chem. Soc.* **63** (1941) pp. 2425-7.

The densities and surface tensions of cis- and trans-decahydronaphthalene were measured from —30 to 180° C. The density-temperature relations are nearly linear, but other measurements deviate somewhat from linearity. The data are presented in tabular and graphical form.

**The Viscosity of Russian and Rumanian Lubricating Oils at High Pressure,** R. B. DOW, J. S. MCCARTNEY AND C. E. FINK, *Jour. Inst. Petr.* **27** (1941) pp. 301-9.

The viscosity of oils increases rapidly with increase of pressure. This effect has been investigated for American oils. The present investigation constituted an extension of the study to lubricating oil from other types of crude. The viscosities of 4 Russian and 3 Rumanian oils were determined at temperatures of 100°, 130° and 210° F. at various pressures up to 46,000 lb./sq. in Data are also given on molecular weight and structural analysis. Viscosities under pressure were determined by a modified form of the rolling-ball viscometer of Hersey. The equation relating viscosity to pressure is not known accurately, but the data of this paper, as well as some other data fit the following relationship resonably accurately:

$$\mu = C\mu_0^{aq}$$

There appears to be little direct relation between viscosity index and the effect of pressure on viscosity. The viscosity slope of the Russian and Rumanian oils are considerably larger than those for typical paraffinic oils. In general the Russian and Rumanian oils have values that on the average are less than those of typical naphthenic samples, but greater than those of typical paraffinic oils.

## Chemical Compositions And Reactions

**The Dehydrogenation of Normal Heptane and Cyclohexane on Cerium, Vanadium and Thorium Oxide Catalysts,** R. A. BRIGGS AND H. S. TAYLOR, *Jour. Amer. Chem. Soc.* **63** (1941) pp. 2500-3.

The investigators studied the aromatization of n-heptane and cyclohexane on ceria, vanadium oxide and thoria catalists. The effect of temperature, the effect of method of preparation of the catalysts, and of deposition on supports and of the reactant feed rate were studied. The order of the aromatization activity is vanadium, cerium, thorium oxides. Vanadium oxide is comparable with but inferior to chromium oxide. Thoria, while possessing dehydrogenating activity, is a poor catalyst for aromatization.

**Nitration of Propane by Nitrogen Dioxide,** H. B. HASS, J. DORSKY AND E. B. HODGE, *Ind. & Eng. Chem.* **33** (1941) pp. 1138-43.

A careful study was made of the nitration of propane by nitrogen dioxide over a wide range of temperature in order to compare this nitrating agent with nitric acid, which is

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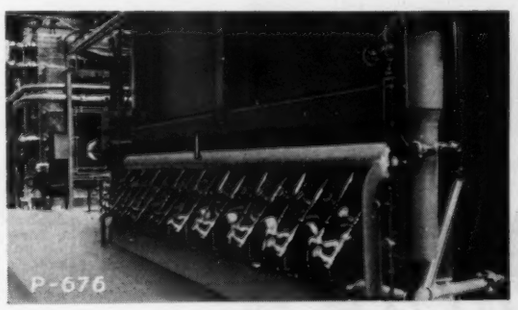


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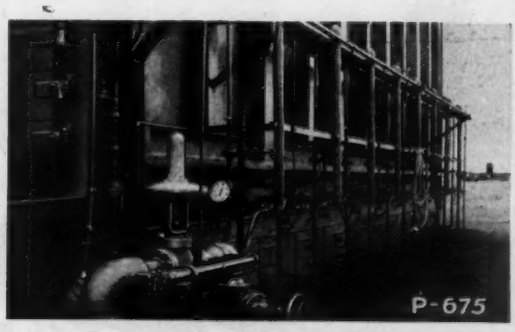


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| Amt. in form of Glucosate | Amt. as dichromate | Application | Saving |
|---|---|---|---|
| | SODIUM BICHROMATE | | |
| 17 pounds | 100 pounds | Calcium Brine | 83 lbs. |
| 17 pounds | 200 pounds | Salt Brine | 183 lbs. |
| 34 pounds | 500 pounds | Cooling Water | 466 lbs. |
| | CHROMIC ACID | | |
| 3 pounds | 66 pounds | Calcium Brine | 63 lbs. |
| 3 pounds | 132 pounds | Salt Brine | 129 lbs. |
| 10 pounds | 330 pounds | Cooling Water | 320 lbs. |

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the reagent employed commercially. Contrary to the reports of certain investigators, nitrogen dioxide and nitric acid yield the same nitroparaffins although conversions are lower with the former reagent. Propane was nitrated in the vapor phase by nitrogen dioxide at temperatures ranging from about 425° to 600° C. in a stainless steel nitrator, and at 248° C. in a glass nitrator. The apparatus is described in some detail. Methods of analysis are given, and typical results of analyses.

## Products: Properties And Utilization

**Physical Aspects of Boundary Lubrication,** O. BEECK, *J. Applied Phys.* **12** (1941) pp. 512-18.

The best criterion for boundary lubrication is that the coefficient of friction shall be independent of viscosity and of the sliding velocity. The areas of contact between sliding surfaces are very small, and as a result the pressure and temperature are exceedingly high at the points of contact. In some instances the temperature may be above the melting point of the metal, which favors plastic flow and local polishing. Long-chain polar compounds may prevent "stick-slip" motion and allow continuous sliding. The addition of wear-prevention agents, such as tritolyl phosphate, gives wear-reduction factors of 5 or more. The addition of oleic acid may still further reduce the wear. The composition and structure of the few molecular layers between the sliding surfaces is the important factor.

**Desorption or "Surface Melting" of Lubricant Films,** D. TABOR, *Nature* **147** (1941) pp. 609-10.

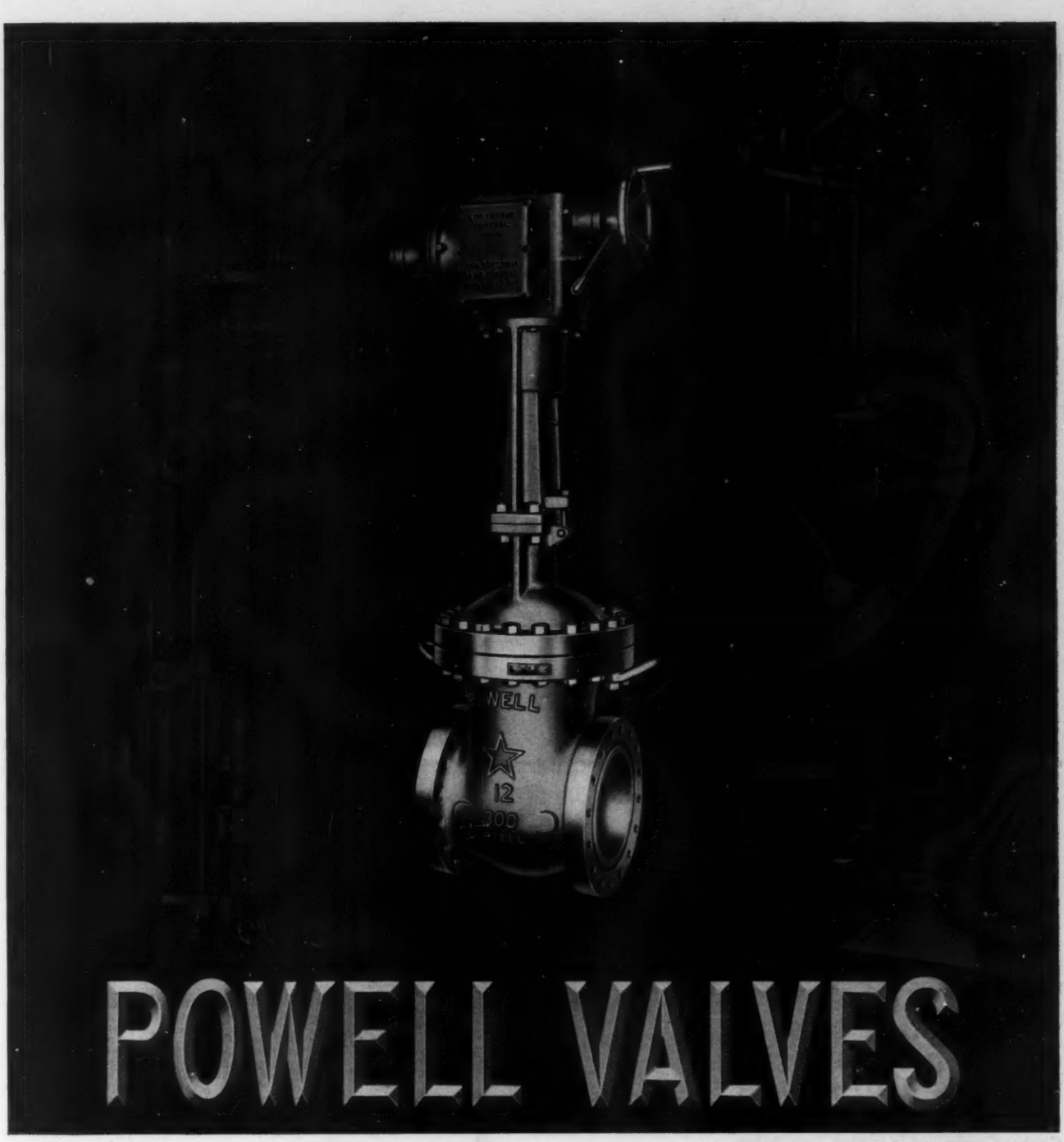
Sliding of lubricated steel surfaces on each other may occur by a continuous or by a "stick and slip" process. The saturated hydrocarbons and the normal alcohols in solid film give continuous sliding; the transition to stick-slip comes at the melting point. In the case of the normal saturated acids from pelargonic to stearic, the transition occurs about 75° C. above the melting point. The transition is caused by the desorption or disorientation of the adsorbed film or to a change of state from closely packed to less-closely packed. The difference between the transition temperature and the melting point of the material is a measure of the strength of attachment of the polar group to the steel surface.

**On the Rate of Reaction in the System Mineral Oil-Oxygen. A Contribution to the Knowledge of Oil Stability,** D. J. W. KREULEN AND D. TH. J. TER HORST, *Jour. Inst. Petr.* **27** (1941) pp. 275-92.

The investigators studied the reaction velocities in the system mineral oil-oxygen. They used an oil of molecular weight 445, density $^{2}_{4}d^{0}=0.8833$, refractive index $D_{20}=1.4828$, critical solution temperature (aniline)=109.0° C. and specific dispersion 158. From these constants the ring analysis of the oil was: aromatic rings 0 per cent; naphthenic rings 37 per cent; paraffinic side-chains 63 percent; extra tertiary carbon atoms 5 percent, and average number of rings per molecule 2.8. They used a method of oxidation in which the oil is agitated violently with an excess of air, so that reaction velocity was measured rather than some composite of velocity and diffusion. They measured the dipole moment as the criterion of oxidation. A definite induction period was found, after which the change in the dipole moment was a straight-line function of time. The influence of the presence of copper and tin was also studied. The main effect of copper was a shortening of the period of induction. Neither copper nor tin had any practical influence on the reaction velocity. Tin also shortens the period of induction, but is less active than copper.

**Some Rheological Problems in Gunned Asphalt,** D. C. BROOME AND L. BILMES, *Jour. Soc. Chem. Ind.* **60 (1941)** pp. 184-90.

The authors describe experiments on strips of gunned asphalt. The strips were extended under known constant stresses for known times and then allowed to recover and strain/time curves were obtained. A model consisting of viscous and elastic elements is proposed for illustrating the behavior of the strips, and certain implications of the model were investigated experimentally. An equation, proposed by Scott Blair and Coppen for shearing stresses, is applied to these tension experiments and is seen to give excellent agreement. The same equation has been applied to torsion experiments and gives almost identical results. Some theoretical and prac-

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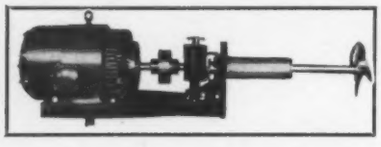

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tical implications of the equation are discussed.

**Sulfur-Asphalt Dispersions,** I. BENCOWITZ, *Ind. & Eng. Chem.* **33** (1941) pp. 1165-8.

Sulfur ground with asphalt and kerosene forms stable suspensions from which aqueous emulsions can be prepared, using a sulfonated alcohol as the emulsifying agent. It is hoped that these emulsions may be found useful in many commercial fields. Applications as insecticides and as ovicides are suggested. Emulsions containing as little as 1.5 percent sulfur or as much as 70 percent remained stable for more than 6 months, either standing on the shelf or with intermittent shaking. The grinding, although conducted in a specially constructed grinder, can be accomplished in any ball mill and the emulsion is formed by hand stirring. Violent stirring is not required. The viscosities of these emulsions seem to be independent of the asphalt concentration, and are determined by a function expressed by the square of the kerosene concentration divided by the product of the sulfur and the water concentrations. The usefulness of these emulsions as insecticides and ovicides is suggested.

**Apparatus and Methods for Precise Fractional-Distillation Analysis,** W. J. PODBIELNIAK, *Ind. & Eng. Chem.,* Anal. Ed. **13** (1941) pp. 639-45.

A column is described that was found satisfactory over the temperature range of —190° to 300° C. The column, flask, reflux, and all connections are vacuum jacketed. Means is provided for compensating the residual heat leakage through the vacuum jacket. Vacuum-jacketed standard-taper ground joints withstand both liquid air and 300° C. temperatures, remaining vacuum-tight and easily detachable. Flexible glass bellows are used throughout as expansion joints for thermal dimensional changes. The column is made of four parts to permit interchangeable use of various distilling tubes and flasks. A new form of precision-spaced wire-type packing was developed for the fullest utilization of capillary reflux liquid films across closely spaced wire turns. This packing has tested as high as 75 plates in 35 cm (14 inches) with the n-heptane and methylcyclohexane system. The low H. E. P. T. and other desirable characteristics are maintained at least up to 35 mm. diameter. Performance data are given for packing of various sizes. This type of packing is now in use in many laboratories for both high- and low-temperature fractionation. Photographs and diagrams are included in the article to illustrate the construction of the various types of columns. Comparison of the Heli-Grid packing with other high efficiency laboratory column packings is included.

**Chemical Factors in the Determination of Water in Insulating Oil,** R. N. EVANS, J. E. DAVENPORT AND A. J. REVUKAS, *Ind. & Eng. Chem.,* Anal. Ed. **13** (1941) pp. 589-92.

The presence of small quantities of water in insulating oil seriously impairs its usefulness in electrical equipment. The need for an accurate as well as rapid method for the determination of water cannot be overemphasized. The authors describe experimental modifications of the combustion procedure directed toward lowering the hydrocarbon correction. The influence of temperature in the removal of the water from oil and the limitations of the Grignard procedure are experimentally demonstrated. An electrical method is briefly described and its application to a field determination of water is pointed out. The data obtained are presented in tabular form. A curve is given showing the relationship between the electrical resistance of the hygrometer and the water content of insulating oils. A tabulation is given showing the solubility of water in new insulating oils at room temperature.

**Analysis of Petroleum Oil-Soluble Sulfonic Acid Soaps,** F. M. ARCHIBALD AND E. L. BALDESCHWIELER, *Ind. & Eng. Chem.,* Anal. Ed. **13** (1941) pp. 608-11.

Petroleum sulfonic acids are produced in the course of sulfuric acid treatments of petroleum distillates, particularly in the manufacture of medicinal white mineral oils, which involve drastic treatment with fuming sulfuric acid. The ordinary acid treatment often employed in refining lubricating oil stocks does not produce sulfonic acids of good quality. Some of the acids remain dissolved in the oil layer. These are called mahogany acids. The others are found in the acid layer, and these are called the green acids. The process used at the Bayway Refinery of the Standard Oil Company of New Jersey for the manufacture and purification of the sulfonate soaps is briefly described. Commercially the oil-soluble sulfonates are available in at least

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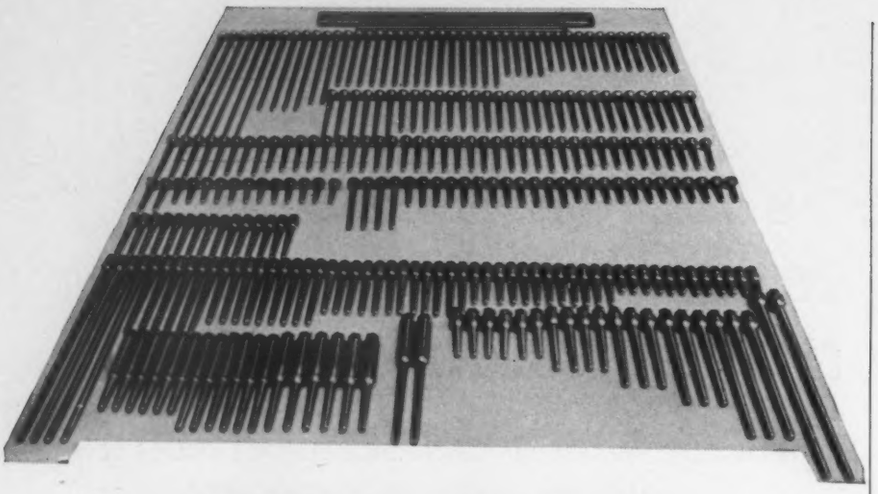

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## Manufacture: Processes And Plant

**Multicomponent Fractionation,** J. J. HOGAN, *Ind. & Eng. Chem.* **33** (1941) pp. 1132-8.

The paper is primarily concerned with the fractionation of a multicomponent system where three components of the feed are distributed between the overhead and bottom products. Such a condition exists in the separation of propane, n-butane, and isobutane, or in the separation of isobutane, isobutylene, and n-butane. A method is presented for determining the distribution of three components of the feed between the overhead and residue at total reflux and at minimum reflux. A method for the calculation of minimum reflux in multicomponent fractionation is developed. Examples are presented that illustrate the method of determining the minimum reflux and the results are compared with other recently proposed methods. An example is given that shows the calculation of the distribution of three components in the feed. Fractionation at total reflux is superior to that at minimum reflux, as is indicated by the comparative separations of the third component.

**The Absorption of Olefins from Ethylene-Nitrogen and Propylene-Nitrogen Mixtures,** E. R. BILLILAND AND J. E. SEEBOLD, *Ind. & Eng. Chem.* **33** (1941) pp. 1143-7.

The development of the synthetic chemical branch of the petroleum industry has created a need for a simpler and more effective method of separating the chemically unsaturated components from cracked refinery gases. The similarities in physical properties of the olefinic and paraffinic components of refinery gases renders their separation difficult and expensive. The high reactivity of the unsaturated molecular structure of the olefins suggests the possibility of exploiting the chemical dissimilarities of the components to effect a less expensive recovery. To this end, a tower 3 inches in diameter and 10 feet high, packed with ⅜-inch Raschig rings, was constructed to study the absorption of the lower olefins in acid solutions of cuprous chloride. The operation of this tower at temperatures of 15° to 30° C. and pressures of 50 to 250 pounds per square inch, using ethylene-nitrogen and propylene-nitrogen gas mixtures containing about 30 percent olefin, successfully demonstrated the effectiveness of cuprous salt solutions for olefin extraction. Eighty percent of the ethylene entering the experimental absorber was extracted at moderate operating conditions. The height of the absorber equivalent to one transfer unit was about 3 feet at liquid rates approximating 5000 pounds per hour per square foot of tower cross section. Liquid film resistance to the diffusion of a complex, copper-containing addition ion controls the absorption rate, diffusion and chemical reaction occurring simultaneously in the liquid film. The apparatus is described in some detail, and a summary is given of the data, and of the calculated results.

**Guaranteeing the Life and Safe Operation of Process Pressure Equipment,** R. C. STRATTON, *Ind. & Eng. Chem.* **33** (1941) pp. 1091-5.

Safety in processing demands that vessels subjected to pressure be correctly designed, properly installed, safely operated, and periodically inspected. The material in process bears an important relationship to the suitability of the vessel, its location, appurtenances, and control. Continuous safe operation requires a definite inspection routine conducted by a competent test engineer. Such inspections provide opportunity for checking corrosion of internal surfaces and clogging or rendering inoperative of pressure release valves, pressure gages, or reducing valves. The result will be longer life of equipment, better efficiency of process, accurate forecasting of the life of objects, and freedom from interruptions and shutdowns. The cost of such procedure is surprisingly moderate. The author discusses these various subjects in the article, including design and operation, inspection personnel, installation testing, and testing and inspection routine.

**Getting the Most from Automatic Control,** J. C. PETERS, *Ind. & Eng. Chem.* **33** (1941) pp. 1095-1103.

In automatic control it is the combined characteristics of controller and process that count. They must be suited to each other. Unsatisfactory results may mean either that a more refined mode of control is necessary or that additional control may be required. Again some simple change in the process may solve the problem. The author gives a brief review of the general theory of control, and follows it by a discussion of what is called the "effective valve characteristic." The ideal time to apply knowledge of control to a process is during the period of design. The subject of valve characteristics is discussed in some detail, and the obtaining of a suitable effective characteristic is concluded.

**The Blending Octane Numbers of Furan and Furfuryl Alcohol,** H. B. NISBET, *Jour. Inst. Petr.* **27** (1941) pp. 293-300.

Furan was added in various concentrations to motor fuel blends of different octane numbers, and it was found that in blends of low octane number the addition of small proportions of furan caused a large rise in octane number. This rise decreased with increasing proportions of furan, and became negligible when the fuel contained 30 percent of furan. The addition of furan to blends of high octane number caused only a slight increase in octane number, and when added to commercial iso-octane, a decrease in octane number was observed. Because of the insolubility of furfuryl alcohol in motor spirit of an aliphatic nature the investigation was limited to the comparison of the blending values of furfuryl and ethyl alcohols in 10 percent blends in spirit containing benzole. The blending octane numbers of furfuryl alcohol in these blends are not as high as those of ethyl alcohol.

**Soybean Lecithin. Stabilizer for Leaded Gasolines,** J. EIDHBERG, *News Ed.* (Am. Chem. Soc.) **19** (1941) pp. 575-6.

The use of soybean lecithin in concentrations of 1-10 pounds per 1000 barrels of gasoline has been found effective in stabilizing leaded and unleaded gasolines against cloud formation, color change, and corrosion of metals. The use of lecithin with a good gum inhibitor such as monobenzyl-p-aminophenol has produced satisfactory results. Cracked gasoline responds more readily than straight-run. The stabilizing effect is caused both by colloidal and inhibitive properties. Aluminum corrodes in gasoline containing lead tetraethyl or dibromacetylene if water is present. This corrosion is inhibited by 10 pounds of lecithin per 1000 barrels of gasoline.

**Adsorption of Saturated Light Hydrocarbons by Activated Charcoals,** B. CRAWLEY, *Jour. Soc. Chem. Ind.* **60** (1941) pp. 205-7.

The adsorption of a series of chemically related pure hydrocarbons (such as paraffins, cycloparaffins, and aromatics), on three specimens of activated charcoals was studied. The relative capacities of the three charcoals, of different densities, illustrate the well-known approximate generalization that optimum volume activity is obtained with a packing density in the neighborhood of 0.35 to 0.40 grams per ml. The results of the experimental work reported throw some light on the adsorptive characteristics of different types of charcoal.

**Aromatics, Gas and Coke from Heavy Petroleum Residues,** E. L. HALL, *Chem. & Met. Engr.* **48** (1941) pp. 100-105.

The author states that petroleum refineries are rarely well situated for the manufacture of aromatic hydrocarbons by the cracking of heavy petroleum residues, since optimum cracking conditions yield large quantities of gas, tar and coke as well as aromatics. It is felt that a gas utility, since it is established for gas making and marketing, is the logical place for aromatic hydrocarbon production. Portland Gas and Coke Company has been a pioneer in this development and has experimented extensively with a variety of residuum cracking processes, one of which has been chosen for used in a $1,250,000 plant now under construction. Another factor favoring this course is a rapidly expanding market for electrode pitch and coke in the Pacific Northwest. The pilot plant work conducted with an oil-gas generator plant with a semi-commercial, tubular type oil cracking unit and with Knowles coke oven is described. Data on yield and on the character of the various products are given. The research program gave the company the choice of several methods for the production of aromatics, and the decision became one of economics. The Knowles coke oven method was finally chosen, because, in addition to producing all of the by-products given by the other methods, it also produces valuable petroleum coke. The commercial plant presently under construction is briefly described.

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It is long since exhibitors, themselves as busy and as eager to serve as you are, have made as great effort to contribute to Industry's needs. By the very fact that these manufacturers are taking time out to exhibit in this busy era, they set themselves apart as a group particularly worth meeting. Isn't that the kind of manufacturer with whom you'd like to do business? See what these exhibitors offer.

The years following the 1941 Exposition will be a critical period in the lives of all who promote production for defense. The wealth of ideas and information made available here will help materially to our progress through the present emergency. This year, attendance is a "must." Don't miss it. Be sure to come — bring your associates.

**18th EXPOSITION OF CHEMICAL INDUSTRIES**

**GRAND CENTRAL PALACE, NEW YORK, DEC. 1-6, 1941**

Managed by International Exposition Co.

**DEDICATED TO SPEEDING UP AMERICA'S INDUSTRY FOR THE DEFENSE PROGRAM**

568

# New Equipment for the Modern Plant

## Stabilog Controller

**THE FOXBORO COMPANY**

The Foxboro Company, Foxboro, Massachusetts, has introduced Model 30 Stabilog Controller, a refinement in design of its line of Stabilog Controllers. While no changes have been made in fundamental principles of operation, the new model has changes for better appearance, refinements and closer control.

**Stabilog Recorder**

All operating adjustments are made from the front of the case, the adjusting mechanisms for change of control point, throttling range, and reset resistance being immediately accessible when the door is opened. But the entire operating mechanism is protected and concealed behind a removable plate. Unit construction simplifies replacement of the measuring system, changing the type of control, or any other major servicing of the mechanism that may be necessary.

Operating features of the new Stabilog Controller are desribed in connection with the instrument's three functions: The first is its proportional function, providing uniform pneumatic proportional action, adjusted to the smallest value that will result in stabilization following a disturbance of process conditions. The reset function, the secondary adjustable controlling function, acts simultaneously with the proportional function, establishing stabilization at the desired point of control. The third function provides a temporary additional correction, determined by the rate of change in any disturbance of conditions. If the rate of change is fast the additional correction is large; if the rate of change is slow the additional correction is negligible. The operation of this third function is entirely automatic, being governed by the proportional and reset adjustments.

## Elastic Stop Nut

**ELASTIC STOP NUT CORPORATION**

Elastic Stop Nut Corporation, 2332 Vauxhall Road, Union, New Jersey, is offering its anchor type nuts for blind mounting applications in general industrial work. The device has been used in aircraft construction. It is designed to provide vibration-proof fastenings for removable plates to cover hand holes and inspection openings.

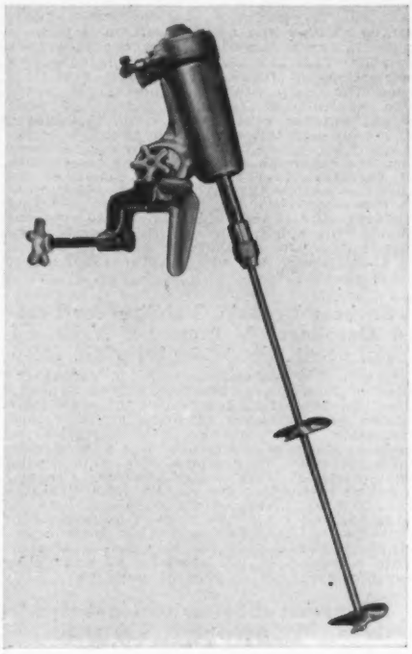
Anchor nuts are riveted to the inside of the structure and bolts, which are inserted from the outside, pass first through the removable plates, then through the structure into the stationary nut.

## Air-Driven Mixer

**MIXING EQUIPMENT COMPANY**

Mixing Equipment Company, Rochester, New York, has introduced two new models, AR-25 and AR-33, of mixers with air-driven motors. They are the first units of this kind offered by the company.

The turbine type air motor is especially designed for agitator duty with built-in muffler and a low rate of air



**Air-Driven Mixer**

consumption. Motors operated at air pressures between 80 and 120 pounds with optimum range between 70 and 80 pounds.

Other features are: adjustable shaft length to fit container sizes, removable shaft for cleaning, sturdy construction with extra ball bearing removing whip load from the motor bearing. A universal clamp permits the unit to be used at any angle. A patent has been applied for on the hand tightening device and one has been issued on the ball and socket clamp. A complete line of accessories includes various types of impellers, support brackets and a full range of metals and alloys for shafts and propellers for use in any liquid.

The air-driven motors are not designed to supplant motor-driven models. For some applications, the air motor is totally inclosed and non sparking and it can not be burned out by overloading.

A throttle permits varying speeds to match mixing requirements. In actual operation the speed of the motor will vary with the load and with variations in air pressure.

Model AR-25 operates at 1750 rpm. The 36-inch shaft and 3-inch propeller are standard. Model AR-33 has operating speed of 400 rpm, 36-inch shaft and 7-inch propeller.


**THE ARMY behind THE DEFENSE PROGRAM**

**PRECISION** — The password for Thermometers acceptable to Government inspectors.

**SOCKETS**
**For Industrial Thermometers**
**For Dial Thermometers**
**For Recording Thermometers**
**For Laboratory Test Thermometers**

All are made to split-hair precision for extreme accuracy and rapid registration of temperature. To pass Government inspection, thermometers and sockets must be made right—for sluggish instruments have no place in the National Defense.

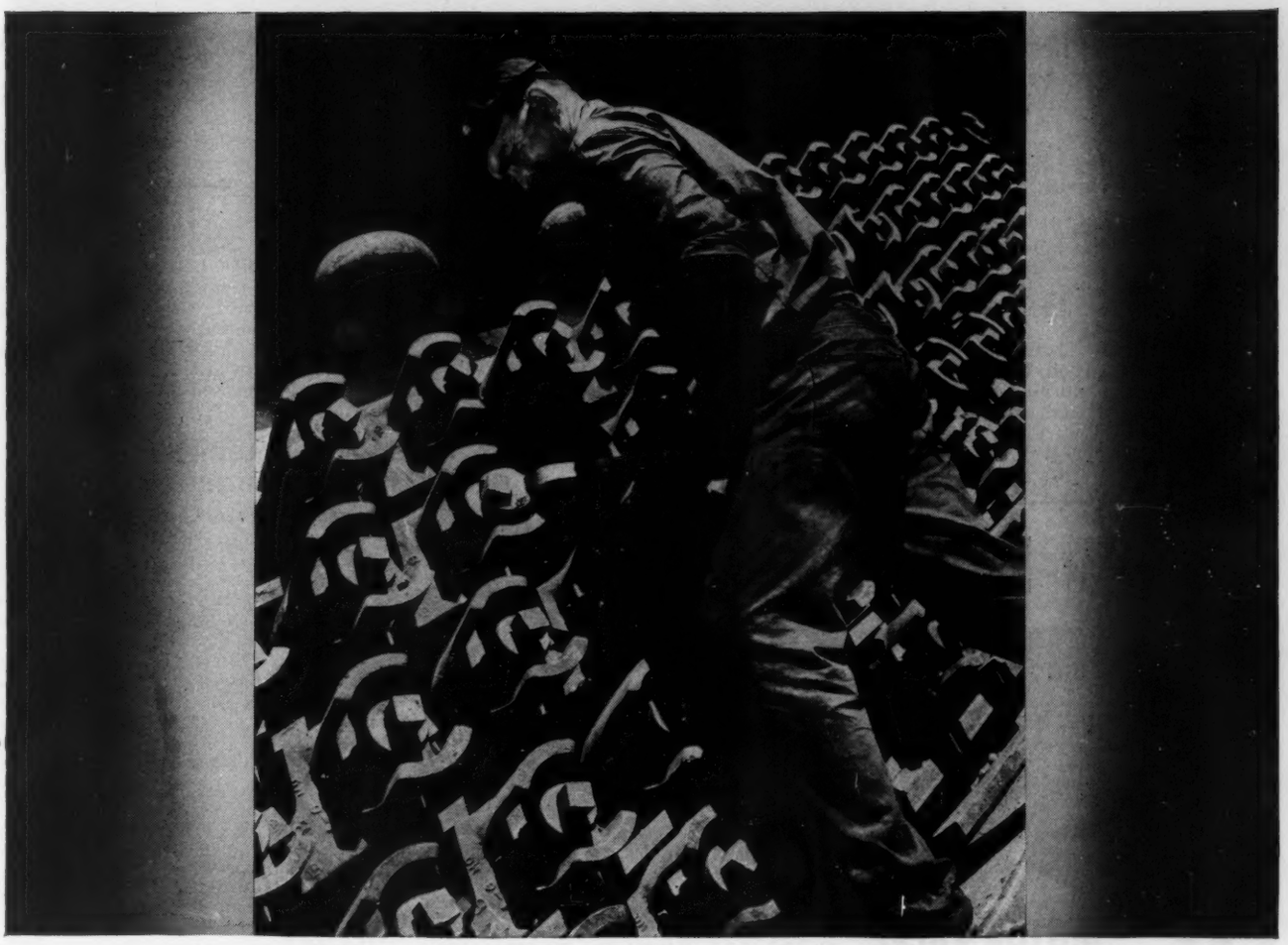
INDUSTRY, serving the Nation's needs, requires the same precision and accuracy. You will find PALMER Thermometers to fill this requirement perfectly. **WRITE FOR CATALOG NO. 300-D.**

**THE PALMER CO., Mfgrs.**

***Industrial, Laboratory, Dial and Recording Thermometers***

**2513 Norwood Ave., Cincinnati, Norwood, Ohio**

**Canadian Plant: King & George Sts., Toronto**



# KEEPING RETURN BENDS OFF THE REPLACEMENT REQUISITIONS

Return bends in an oil refinery can be either a direct aid to economical operation or a constant drain on the maintenance account. Into which classification they fall depends on the service they give and the frequency with which they appear on replacement requisitions.

Return bends made from 4-6 per cent Chromium-Molybdenum steel qualify in the first category. The steel has good corrosion resistance and retains its strength at elevated temperatures. The Molybdenum content eliminates temper brittleness.

All three qualities are important from the service standpoint, the last named particularly so. It means that bends can be safely cooled to ambient temperatures before removal for cleaning.

Chromium-Molybdenum is one of several Molybdenum steels which are demonstrating their value in day-after-day refinery operation. Complete data on them is contained in our book, "Molybdenum in Steel", a copy of which will be sent free on request to those interested in improved materials.

CLIMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.
MOLYBDIC OXIDE—BRIQUETTED OR CANNED • FERROMOLYBDENUM • CALCIUM MOLYBDATE

**Climax Molybdenum Company**
**500 Fifth Avenue • New York City**

**MOLY**

## Combination Burner

**JOHN ZINK COMPANY**

John Zink Company, Tulsa, Oklahoma, is now offering Roto-Gas Burner, a combination unit for either gas or oil.

It has stationary gas jets with at least ⅛-inch diameter ports with no stuffing boxes. Its small rotor prevents even small deposits of sulphur, salt or carbon from having much effect in disturbing the balance of the wheel. Noise has been reduced at least 40 percent. Each of the eight gas jets has a separate control cock.

A hollow center shaft makes it possible to install an oil burner through the center. When burning oil, steam is the motive power and all but two jets are cut off.

The rotor, fan and shaft are light weight, which allows use of a light weight bearing, which is removed far enough from the heat zone to allow air to be drawn into the hollow center shaft to provide ample cooling of moving parts.

**Zink Roto-Gas Burner**

The design is such that parts can be quickly removed for cleaning or for changing the angle of impact.

## Tube Pressure Gauge

**BROWN INSTRUMENT COMPANY**

Brown Instrument Company, Wayne and Roberts Avenues, Philadelphia, has designed a new rectangular case Bourdon tube pressure gauge to match other items in its line of rectangular case instruments. The gauge has a recalibrator which provides a means for easily and accurately setting the pen at zero. In addition, there is a micrometer zero adjustment on the pen arm itself.

The methods of construction, consisting of a one-piece casting supporting the Bourdon tube, the gear and pinion, and the pen arm shaft, make it possible to have the whole assembly installed in the case as one completely calibrated unit. This construction simplifies the replacement problem.

A particularly important feature of the new gauge is the method of sealing the ends of the stainless steel tubes which are used in the gauge for certain pressure ranges. With this method of sealing, the heat-treatment and original calibration of the tube cannot be affected, as might be the case if the tubes were closed by welding.

Another important constructional advantage of the new gauge is the use of dissimilar metals at the bearing surfaces. Pinions and shafts are made of stainless steel and bushings are made of a high Brinell test monel.

Accuracy during operation is assured by the wide hob cut pinion and the heavy gear segment. All of the connecting links and levers are made from stainless steel to avoid corrosion and all bearings are bushed.

## Microphotometer

**LEEDS & NORTHRUP COMPANY**

Leeds & Northrup Company, 4934 Stenton Avenue, Philadelphia, has announced a new recording microphotometer, a rapid and convenient method for analyzing spectrographic plates or films in research and industrial laboratories. Because the plates or films are mechanically scanned by a motor-driven scanning unit, and the relative positions and densities of spectrum lines are automatically recorded by an L&N Speedomax Recorder, this new recording microphotometer eliminates the eyestrain and "human equation" of visual methods, and does away with the delays and limitations of photographic processes. Quick determinations of elements present in small percentages are made possible by pen-and-ink records of standard and test spectrograms drawn at high speed on one chart.

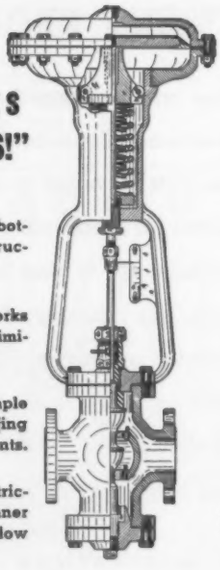
Designed to accommodate plates or films as large as 4 inches high by 10 inches wide, the scanning unit includes on a heavy cast base, an optical system, a plate stage, a drive mechanism for the plate stage, an a-c operated amplifier and all necessary controls grouped at a convenient location. In indicating and recording relative positions and densities of spectrum lines, the response


SEND FOR BULLETIN 41-A

ON THE

NEW H-W Type 86 MOTOR VALVE

WITH THE 4 FEATURES THAT ARE "NEWS!"



1 Improved top and bottom guided inner structures.

2 Advanced top works with roller guide eliminating friction.

3 Yoke styled with ample room to repack stuffing box or mount attachments.

4 Minimum body restriction permitting inner valve to dominate flow through travel.

BODY ASSEMBLIES FULLY REVERSIBLE WITHOUT ADDITIONAL PARTS OR SPECIAL TOOLS

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Now—more than ever before—refiners recognize the money saving advantages of our corrosion resisting Pumps, Pipe, Valves, Fittings and Tanks. You, too, can enlist these products in the fight against unnecessary refinery operation costs.

Present day refining demands a thorough knowledge of many corrosion resisting materials and their application. Our recommendations are based on actual experience in the field of service.

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- Dubbs Thermal Cracking Units*
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- Toluene Extraction from Cracked Gasoline
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- Gas Recycling Plants
- Natural Gasoline Absorption Plants
- Pipe Still Heaters

*Subject to License from Universal Oil Products Company

# MID-CONTINENT ENGINEERING CO., INC.

**DALLAS, TEXAS**

of the Speedomax recorder to density changes is so immediate and so rapid that in less than 1.5 seconds the pen moves from one position and comes to rest at its new position—even across the entire width of the 9-inch chart. Pen position can be read at a glance on an indicating scale as the record is being drawn. No unusual skills are required to operate this new microphotometer. Anyone familiar in a general way with instruments can quickly learn to use it.

## Gas Pocket Guide

**BASTIAN-BLESSING COMPANY**

Bastian-Blessing Company, 4201 Preston Avenue, Chicago, has compiled a reference manual for the liquefied petroleum gas industry. It contains basic data, charts, tables and other information, which coordinates technical and specialized information in connection with the handling of these gases.

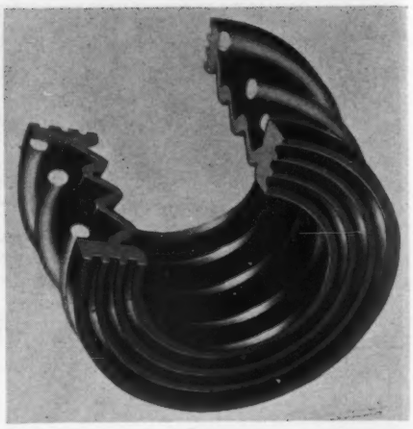
## Pump Seal

**CRANE PACKING COMPANY**

Crane Packing Company, 1800 Cuyler Avenue, Chicago, has announced the new bellows-type Seal, listing the following as principal features:

Seal has only 2 parts: bellows and spring. Bellows is an exclusive synthetic rubber compound found to be excellent for sealing services; grease, oils, salt water, alcohols and anti-freeze do not affect it. Installed partially compressed; ready for instant seal.

Entire unit (bellows and spring) is spring driven and operates as a driving coupling. Seal does not touch or have a sliding contact with the shaft: rust, corrosion and deposit do not interfere with or reduce efficiency. Bellows connects two flanged ends. Spring is placed in a fixed position against the inside shoulders of the flanged ends and so holds the contact facings against the sealing washer on the one end and the driving base on the other.



**Crane Pump Packing**

Because of the seal's ability to flex and compress as a unit, pressure variation, misalignment, fan thrust, torque or vibration set up by an unbalanced impeller, are automatically accommodated or compensated for. The serrated contact facings are responsible for the positive seal at both the washer and driving base points. These facings are formed in a series of concentric grooves and flat-faced ribs, effecting seal with a suction-action.

Among other advantages is "blindfold" installation. Seal cannot be installed wrong either on the assembly line or in the field. Both ends are identical—either end is right.

## Meter

**WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY**

Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania, has announced a new combination watt-hour and thermal demand meter, especially developed to meet continued extension of demand rates to smaller loads, available in standard house size, case and mounting.

With a-c ratings of 5, 15 and 50 ampere capacities, 120 to 240 volts, 2 and 3 wire for reading up to 20 kilowatts, the unit is similar to the ordinary watt-hour meter in general appearance.

The watt-hour mechanism has standard adjustments for full load, light load, and power factor; the thermal unit has only 2 adjustments for zero and for full scale.

## Dual Pump Drives

**PEERLESS PUMP COMPANY**

Peerless Pump Company, 301 West Avenue 26, Los Angeles, has designed an auxiliary drive for deep well turbine pumps.

Normally equipped with electric motor head, the secondary drive may be by right angle gear, powered by a gas, gasoline or Diesel engine or steam turbine. In the event of interruption of electric service, the stand-by plant can be started instantly, either by the operator or by completely automatic control, thus providing a never-failing source of supply.

Other types of dual-drive pumps have steam turbines as primary power, with internal combustion engines connected with the secondary right angle gear. Either source of power operates independently of the other.


**AQUA AMMONIA NH₄OH**
Colorless, clear solution with pungent ammonia odor. Specific gravity at 15°C....0.89; Baumé ...26° -26.5°. Freezing point, below -40°F.

**SULPHUR DIOXIDE, $SO_2$**
Colorless gas at normal temperatures and pressure, liquefies at -10°C. at atmospheric pressure.

**CAUSTIC POTASH, KOH**
In three forms. Liquid: Colorless to dark, somewhat opaque, viscous solution. Solid: Dense, dark, opaque, deliquescent solid. Flake: Dense, dark, opaque, deliquescent flakes, practically free from dust.

# Bear Brand

**CHEMICALS INDISPENSABLE TO THE REFINING INDUSTRY**

Manufactured under strict laboratory control, BEAR BRAND chemicals are well known to western refiners for their purity and uniformity. They are products of the Great Western Division of Dow—the largest plant of its kind on the Pacific Coast. An ever increasing number of refiners, conversant with these facts are specifying BEAR BRAND chemicals and taking advantage of the unequalled facilities offered by Great Western.

**GREAT WESTERN DIVISION**
**THE DOW CHEMICAL COMPANY**
San Francisco, California, U. S. A.
*Plants:* Pittsburg and Seal Beach, California
New York • Seattle • Los Angeles

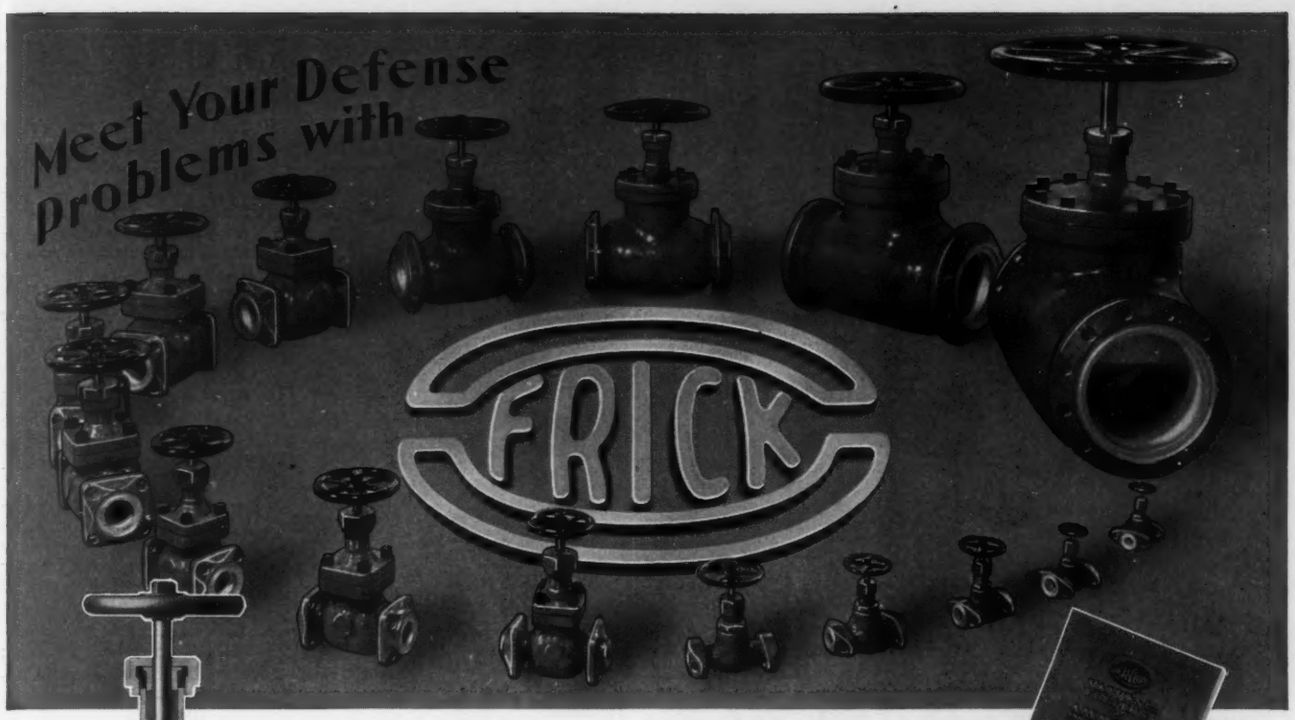
*Working with you for America*

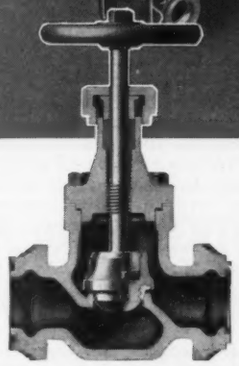
GREAT WESTERN DIVISION • BEAR BRAND PRODUCTS • THE DOW CHEMICAL COMPANY — DOW

**CAUSTIC SODA, NaOH**
Supplied in 3 forms Liquid: Colorless, semi-opaque viscous solution. Solid: Dense, white, opaque, deliquescent solid. Flake: Thin, white, opaque, deliquescent flakes, practically free from dust.

**LIQUID CHLORINE, $Cl_2$**
Liquefies at -34.6°C. at atmospheric pressure. Not over 1.4 lbs. moisture per ton. Total residue not over 15 grams per 100 lbs.

**ANHYDROUS AMMONIA, $NH_3$**
Colorless gas with extremely pungent odor at normal temperatures and pressure. Liquefies at -33.4°C. at atmospheric pressure. Specific gravity at 0°C. and one atmosphere 0.596; boiling point -33.4°C.



# Semi-steel Valves

They hold pressures up to 300 lb. gage—whether handling ammonia, Freon-12, methyl chloride, $CO_2$ or natural gas, at normal or low temperatures. Only in Frick valves do you get the patented high-angle seat, alloy-faced button, and easy repacking which have given them the preference for generations. . . . Full range of sizes, ¼" to 14". Screwed valves up to 2". Stocked by Frick Distributors in principal cities everywhere . . . Ask for Catalog K . . . Your copy is waiting: Write to **FRICK CO.**, Waynesboro, Pa.

# A FASTER, CHEAPER METHOD OF CLEANING PROCESSING EQUIPMENT

For cleaning heat exchanger bundles, cooling or heating coils, pumps and machinery, truck chassis, floor and stair treads and any place where heavy dirt and grease accumulate.

All that is needed is a source of steam at 50 to 125 lbs. pressure and unheated water at any pressure over 15 lbs. It converts these pressures together with a solvent into a high pressure hot water cleaning jet with up to 270 lbs. nozzle velocity.

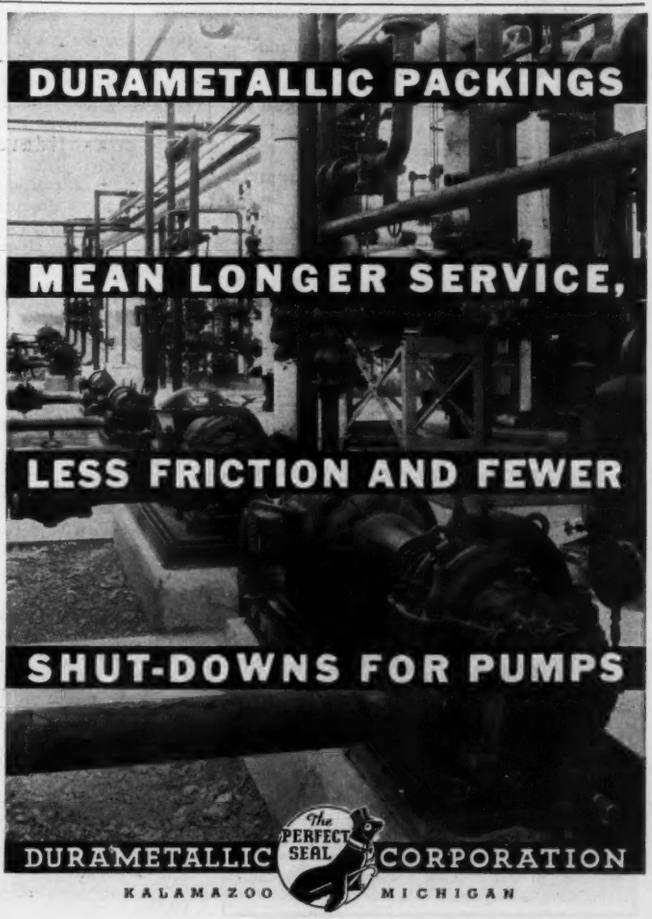
**SELLERS HI-PRESSURE CLEANING JET**

180°–190° temperature of jet softens grease, wax, tar, etc.

200 lbs. – 250 lbs. pressure has two or three times cutting power of fire line pressures.

*Write for details*

**WILLIAM SELLERS & CO., Inc., 1609 Hamilton St., Phila., Pa.**

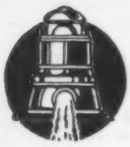



DURAMETALLIC CORPORATION

The PERFECT SEAL

KALAMAZOO MICHIGAN

# A COOL MILLION and A Half Gallons Per Day



**OVER IN a certain New York town an important airplane gun manufacturer suddenly needed a lot of water for plant operation. No one knew exactly what the water bearing formations below would produce. It was no time to consider the inexperienced. Layne engineers were called in, advised of the urgency and authorized to proceed without delay. In a very few days, the job was completed; well drilled, casing set, pump installed and testing concluded—producing a cool million and a half gallons of water per day. The manufacturer was highly pleased and from somewhere a bottle of champagne was produced and a proper christening took place.**

**To that manufacturer a very unusual feat had been accomplished. To Layne men, it was just another in a long series of such incidents. In the present day National Defense Emergency, no Layne well water producing undertaking has met with failure. The majority have greatly exceeded the production specified.**

**No firm in the Americas—north or south, is so adequately equipped or widely experienced in designing, manufacturing and installing well water systems. If you need more water, write or wire,**

**LAYNE & BOWLER, INC.**
**Memphis, Tenn.**

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## *PUMPS & WELL WATER SYSTEMS*

**AFFILIATED COMPANIES**

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| Layne-Central Co. | Memphis, Tenn. |
| Layne-Northern Co. | Mishawaka, Ind. |
| Layne-Louisiana Co. | Lake Charles, La. |
| Layne-New York Co. | New York, City. |
| Layne-Northwest Co. | Milwaukee, Wis. |
| Layne-Ohio Co. | Columbus, Ohio. |
| Layne-Texas Co. | Houston, Texas. |
| Layne-Western Co. | Kansas City, Mo. |
| Layne-Western Co. of Minnesota | Minneapolis, Minn. |
| International Water Supply | London, Ontario, Can. |


# BUSINESS NOTES

Edwin A. Wert has been elected vice president in charge of engineering and sales of the power piping division of Blaw-Knox Company, Pittsburgh. He takes the position held formerly by S. J. Harrell. Wert has been a consultant of the Blaw-Knox organization for several years and came to the new divisional executive position from the Detroit Edison Company, where he has been engaged in engineering and design work for 18 years. Wert is known for his work on piping design and recently developed, in behalf of Blaw-Knox Company, a simplified formulae for determining the stresses in power piping systems. He is an alumnus of the University of California, a member of the American Society of Mechanical Engineers and has served as a lecturer at the Detroit Institute of Technology.

**E. A. Wert**

William G. Hamilton, Jr., has been promoted to assistant manager of the Philadelphia factory and sales territory of American Meter Company. Hamilton joined the organization December 1, 1927, after graduation from Swarthmore College. He was first with the Helme & McIlhenny factory, which later was consolidated with the John J. Griffin & Company into the American Meter Company. Since then he has applied himself extensively to solution of problems in pressure regulation, flow measurement and flow control. He will continue work along these lines in his new capacity.

**W. G. Hamilton, Jr.**

J. L. Rosenmiller has been selected to manage the new accessory equipment and repair department of York Ice Machinery Corporation, York, Pennsylvania. He came to the company in 1923 as president of York Oil & Chemical Company, which in 1927 was merged with the parent organization. He then became manager of the accessory equipment and supplies division and for the past 11 years has been manager of the sales promotion department. Rosenmiller was graduated from Lehigh University in 1920 after which he was with Empire Gas & Fuel Company, Bartlesville. He was with Henry L. Doherty & Company until 1923.

**J. L. Rosenmiller**

Manly B. Brown has been appointed manager of sales, pipe division, Republic Steel Corporation. Brown has been with Republic since December, 1936, as assistant manager of sales, pipe division. He formerly was associated with Wilson & Bennett Manufacturing Company as eastern sales manager, and prior to that was Chicago representative of Ohio Corrugating Company. For 8 years he was in the Chicago sales department of Wheeling Steel Corporation.

Five vice presidents have been added to the executive staff of General Electric Company, Walter R. G. Baker, Chester H. Lang, David C. Prince, Elmer D. Spicer and Harry A. Winne.

The new officers were elected in connection with a major change in the company's organization. Under the new setup, the company will have four major operating departments: Appliance and Merchandise, under Vice President Hardage L. Andrews; Radio and Television, under Vice President Baker; Lamp, under Vice President Joseph H. Kewley; and the Apparatus Department which, because of its great volume of business and diversification of products, will be staffed by five vice presidents, whose duties will be along functional lines. These Vice Presidents are: Lang, in charge of defense activities and also continuing as Manager of Apparatus


**FOR SALE**
***For Immediate Delivery***

**Two New 26-lb. natural gasoline storage tanks of 25,000 gallons capacity each, 10′ diameter by 40′ long shell with hemispherical heads, complete with 3′ high support saddles, all necessary connections, tanks built in accordance API-ASME code of new material in September, 1941, have never left fabricating plant and may be inspected before shop painted. Price f.o.b. Shreveport, Louisiana, $3,100.00 each.**

**Box 777, c/o The Refiner, Houston, Tex.**

# QUICK TURBINE REPAIRS

If you need dependable turbine repairs **in a hurry,** call us. We are completely equipped to repair and dynamically balance turbine rotors and any high speed rotating elements in our modern shops.

**25 Years Successful Experience**

**GULF ENGINEERING CO., INC.**
*"Service, Not Promises"*
7014 NAVIGATION BLVD. HOUSTON, TEXAS
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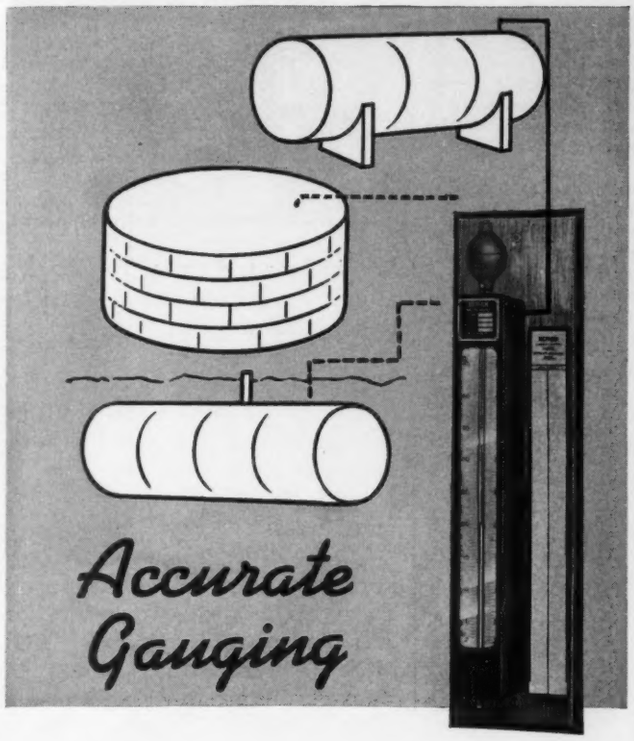



## OF OPEN VENTED OR PRESSURE—GROUND LEVEL, UNDERGROUND, OR OVERHEAD TANKS . . . .

• Meriam Tank Gauges are substantially built accurate gauges for determining the liquid level of oil, water, or any other liquid. They are suited for use with large or small tanks regardless of location, and are not expensive.

These gauges are of the distant reading type, permitting the gauge to be placed in a sheltered convenient place, such as the superintendent's office. They operate by balancing with air pressure the head of liquid to be measured. No gears, levers, or diaphragms are used, avoiding maintenance and upkeep. Bulletin No. 20, giving complete engineering and operating description sent on request. Send for a copy.

**THE MERIAM CO.**
CLEVELAND, OHIO

**Manometers, Meters, and Gauges for the accurate measurement of Pressures, Vacuums and Flows of Liquids and Gases.**

## PALMETTO PETE *says*

A little sober thought will show that continuous lubrication makes packing last longer. A test will prove it! Write for a

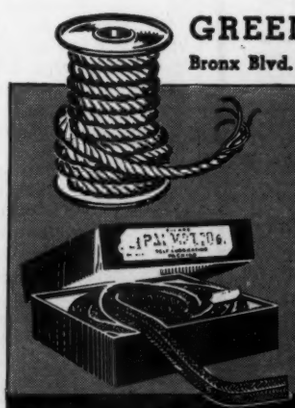
**FREE working SAMPLE**

today. Just send name, address and specify service conditions and size of packing

*REG. U. S. PAT. OFF.

## PELRO* *Stays* SOFT

One of the secrets of Pelro's extra-long life is the special lubricant unaffected by solvents and impregnated in every strand before braiding. This reserve supply deep in the heart of the packing keeps the contact surface continuously supplied. As a result, Pelro stays soft, does not require frequent tightening, and lasts from two to three times longer than ordinary packings. Try Pelro — you'll find you'll save both time and money.



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Sales; Prince, in charge of application engineering — Apparatus Department; Earl O. Shreve, in charge of commercial activities, Apparatus Department; Spicer, in charge of manufacturing—Apparatus Department; and Winne, in charge of design engineering—Apparatus Department.

Vice President William R. Burrows, formerly in charge of general manufacturing operations, and Vice President Roy C. Muir, formerly in charge of general engineering operations, will become members of the president's staff, carrying out assigned duties in these respective fields.

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J. H. Watters on November 1, was elected president of Union Asbestos and Rubber Company, succeeding L. L. Cohen, who was elected chairman of the board of directors. Mr. Watters was formerly general manager of the Marion Steam Shovel Company, Marion, Ohio. Born in Norfolk, Virginia, January 30, 1885, Watters attended Norfolk High School and the University of Virginia. He started his business career with Watters & Martin Wholesale Hardware Company, Norfolk, in 1905 and was with them continuously until December 31, 1925. On January 1, 1926, he became vice president and manager of sales of New York Air Brake Company and remained there until October 31, 1929. He then became president and general manager of The Marion Steam Shovel Company, Marion, Ohio.

**J. H. Watters**

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Yarnall-Waring Company, Philadelphia, has announced the following changes in the sales organizations: C. Wilson, Jr., formerly of the New York office, has been appointed district manager of Pittsburgh-Cleveland territory and C. N. Maxfield, district manager of Detroit territory, covering Michigan and western Ohio. Bernard R. Bristol and Charles H. Grosjean have joined the New York sales staff, A. E. Robinson, the Chicago sales office, and A. L. Aicher, for years a member of the factory engineering staff, the Philadelphia sales office.

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Russell E. Day, who has been district manager for Wico Electric Company in the Southwest, has been appointed assistant manager of manufacturing sales and transferred to headquarters at Springfield, Massachusetts.

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Earl C. Maund has joined the engineering and sales staff of Manning, Maxwell & Moore, Inc., in the Chicago office. His engineering services will cover Consolidated safety valves, Hancock valves, American instruments and Ashcroft gauges. Maund formerly was in the engineering department of Sinclair Refining Company at East Chicago, Indiana, and with Arkansas Fuel Oil Company at the Shreveport plant.

---

Anker Winther, assistant sales manager of York Ice Machinery Corporation, will supervise activities of the combined advertising and sales promo-

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12. **Gives longer life.**

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THE RIDGE TOOL CO., ELYRIA, OHIO

*All-alloy heavy-duty. Sizes 6" to 60". ... Millions in use.*

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**WORK-SAVING PIPE TOOLS**

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WESTON all-metal thermometers are guaranteed accurate within 1% over the entire scale, and are available in types, ranges, scale diameters and stem lengths to suit many industrial applications.

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The *practical* lab thermometer. Has large, easy-reading scale. Stainless steel construction. Accuracy, ½ of 1% over the entire scale. Ask for bulletin.

**WESTON ALL-METAL GAUGE-TYPE THERMOMETERS**

● **Pipe or fittings . . . it makes no difference to "Vulcan Superior," the universal service tong. You can switch from one to the other without adjustment or change of parts. And "Vulcan Superior" is the only chain tong with *reversible* pipe - and - fittings jaws. When one set of teeth begins to wear simply remove the Through-Bolt and reverse the jaws. Seven sizes, with either Flat Link or Cable chain, for pipe and fittings ⅛ to 12 inches. See our advertisement in the Composite Catalog. Buy from your supply store.**

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*Headquarters for*

**Drop - Forged Wrenches (Carbon and Alloy), Detachable Socket Wrenches, Reversible Ratchet Wrenches, Tool Holders, "C" Clamps, Lathe Dogs, Eye Bolts, Hoist Hooks, Thumb Nuts and Screws, Chain Pipe Tongs and Vises.**


tion work, which has been consolidated at company headquarters, York, Pennsylvania. Frank Chalmers, who formerly handled advertising exclusively when this department was in New York, will continue to specialize in advertising and will have a part in sales promotion.

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R. M. Cundiff has been appointed manager of the Cincinnati office of Bailey Meter Company, Cleveland. He succeeds E. E. Dearborn who resigned August 1. For the past 12 years he has been in the New York office of the company where he devoted most of his efforts to application of metering and control equipment in steam power plants and industrial processes. His assistants in the Cincinnati territory are J. A. Lucas and J. E. Zimmerman.

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Walter B. Hawkinson has been elected to the joint position of secretary-treasurer of Allis-Chalmers Manufacturing Corporation, Milwaukee. This has added the duties of secretary to his work. He took over the duties of William A. Thompson, treasurer, who resigned recently. The new secretary started with Allis-Chalmers organization 34 years ago in the treasurer's department. In 1926 he became assistant manager of the tractor division, after which he played an important role in the rapid expansion of the company's agricultural trade. Returning to the treasurer's department in 1936, Hawkinson was elected its head. Thompson's resignation terminated 40 years of service. Beginning as a general bookkeeper in the accounting department, he was later appointed chief accountant. In 1907 he was elected comptroller and in 1923 he was made secretary in addition. He relinquished the office of secretary when he was made a vice president in 1932, but again assumed the duties of secretary in 1936, retaining this office with the position of vice president until his resignation.

## Chemical Company Name Is Changed

The name of the Hydrocarbon Chemical and Rubber Company, owned jointly by B. F. Goodrich Company and Phillips Petroleum Company, has been changed to Hycar Chemical Company. The firm is now manufacturing synthetic rubber at Akron, Ohio, and has begun construction of another plant near Louisville, Kentucky.

## Vinson Supply Company Has West Texas Store

Vinson Supply Company, Tulsa, Oklahoma, has opened a new store at Odessa, Texas, which will service plants in West Texas and New Mexico.

Louis Barnett is in charge of the territory and Robert Searls is in charge of the warehouse. The address is 912 North Grant street.

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**GRATING FLOORS AND SAFETY STEPS**

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